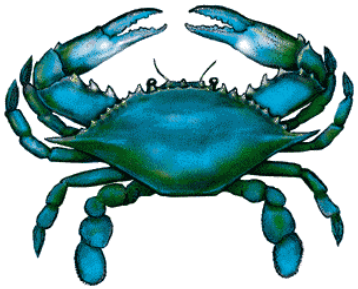
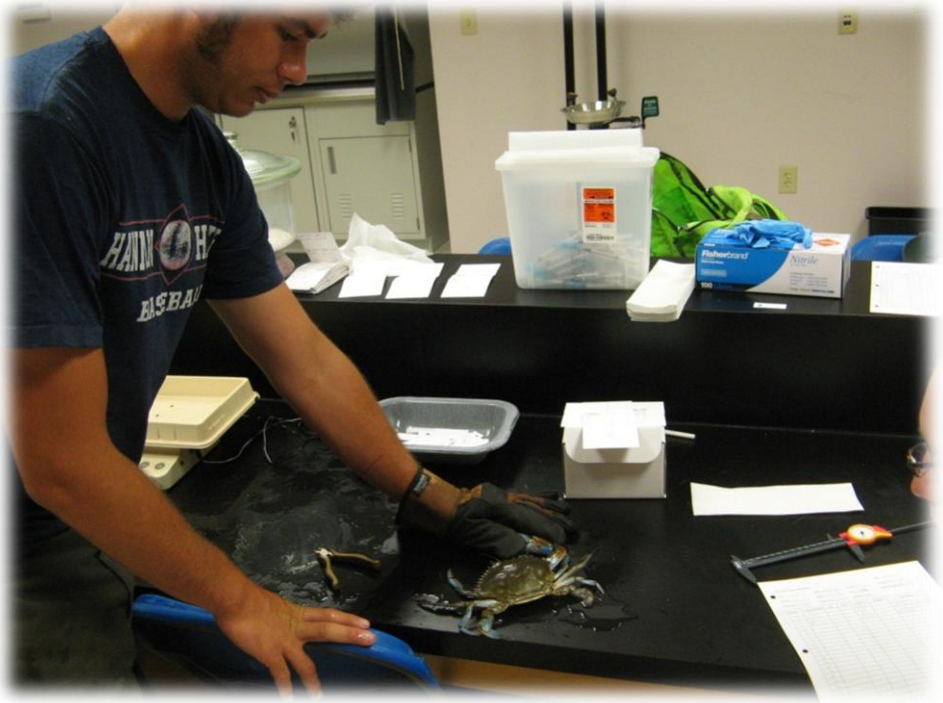
Dying of Thirst: Impact of Reduced Freshwater Inflow on South Carolina Blue Crabs

Michael Childress & Kirk Parmenter
Clemson University



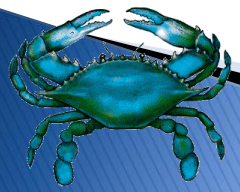

MUD RUN



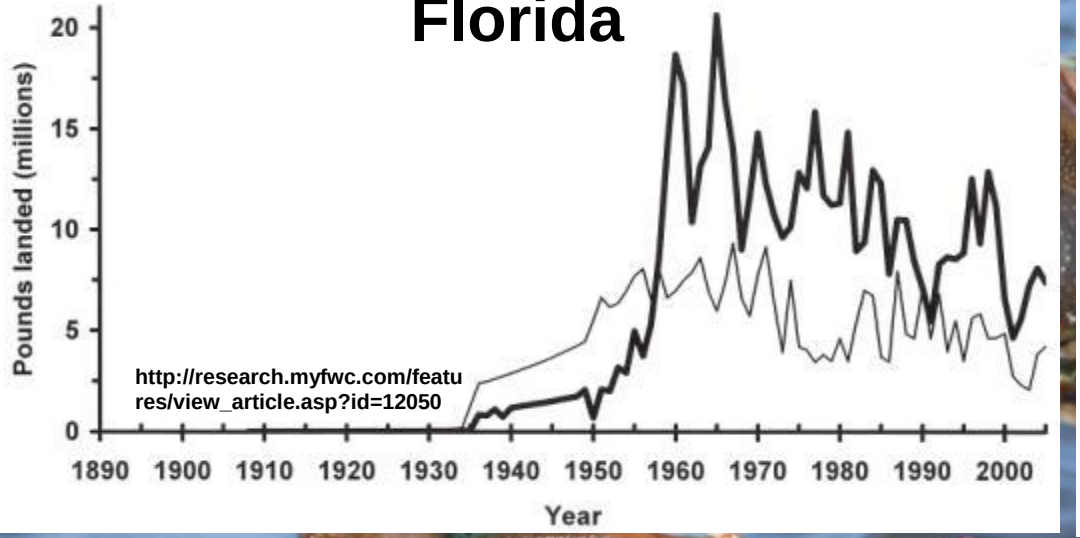

ACE
National Estuarine
RESEARCH RESERVE

Presentation Outline

- **Identification of the Problem – Dying of Thirst**
- Crab Life History – Why Salinity Matters
- ACE Basin National Estuarine Research Reserve
- Patterns of Water Quality in Relation to Inflow
- Hypotheses Linking Crab Decline and Drought
- Forecasting the Future
- What Can Management Do?

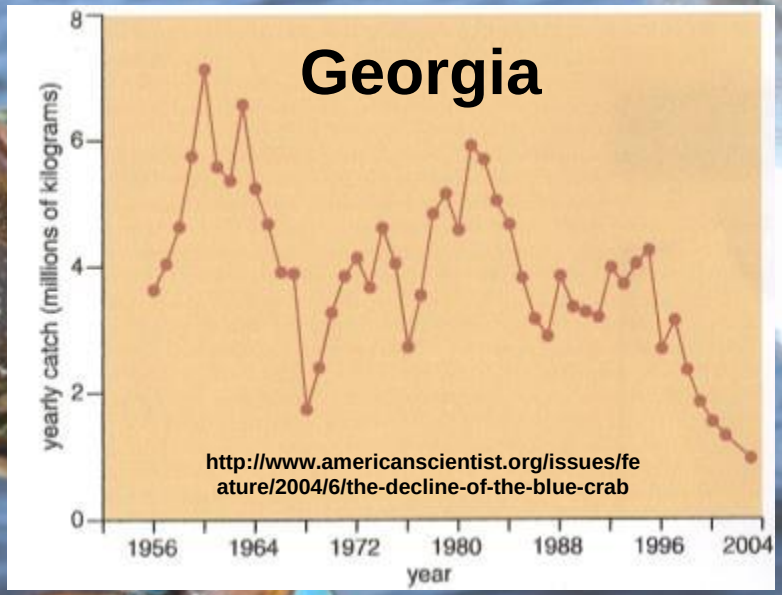


Florida



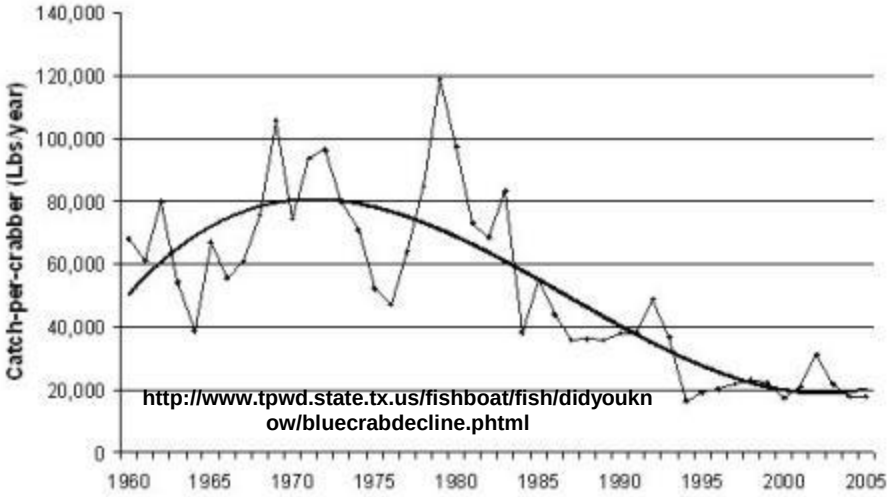
http://research.myfwc.com/features/view_article.asp?id=12050

Georgia



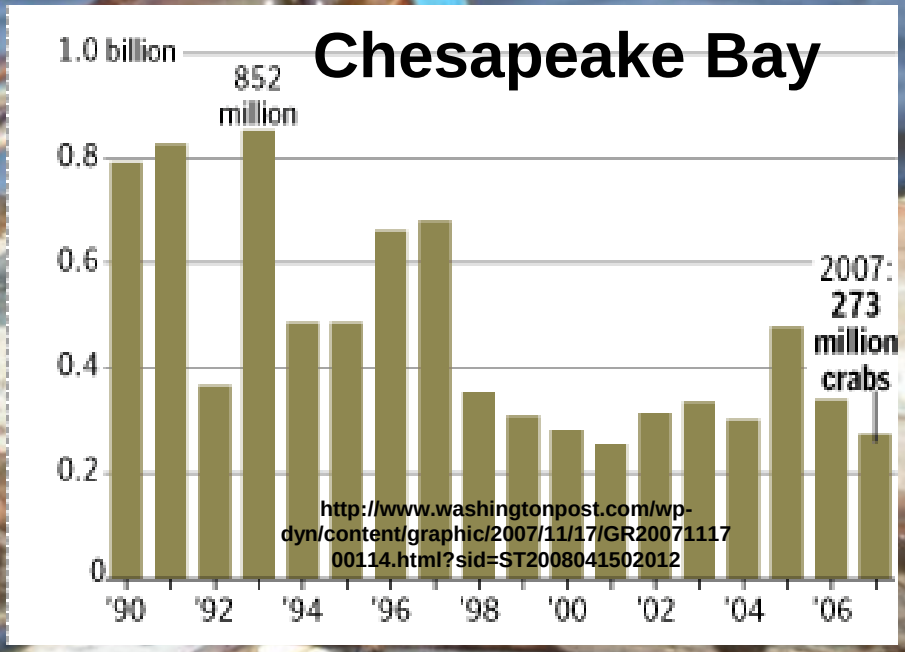
http://www.americanscientist.org/issues/feature/2004/6/the-decline-of-the-blue-crab

Texas



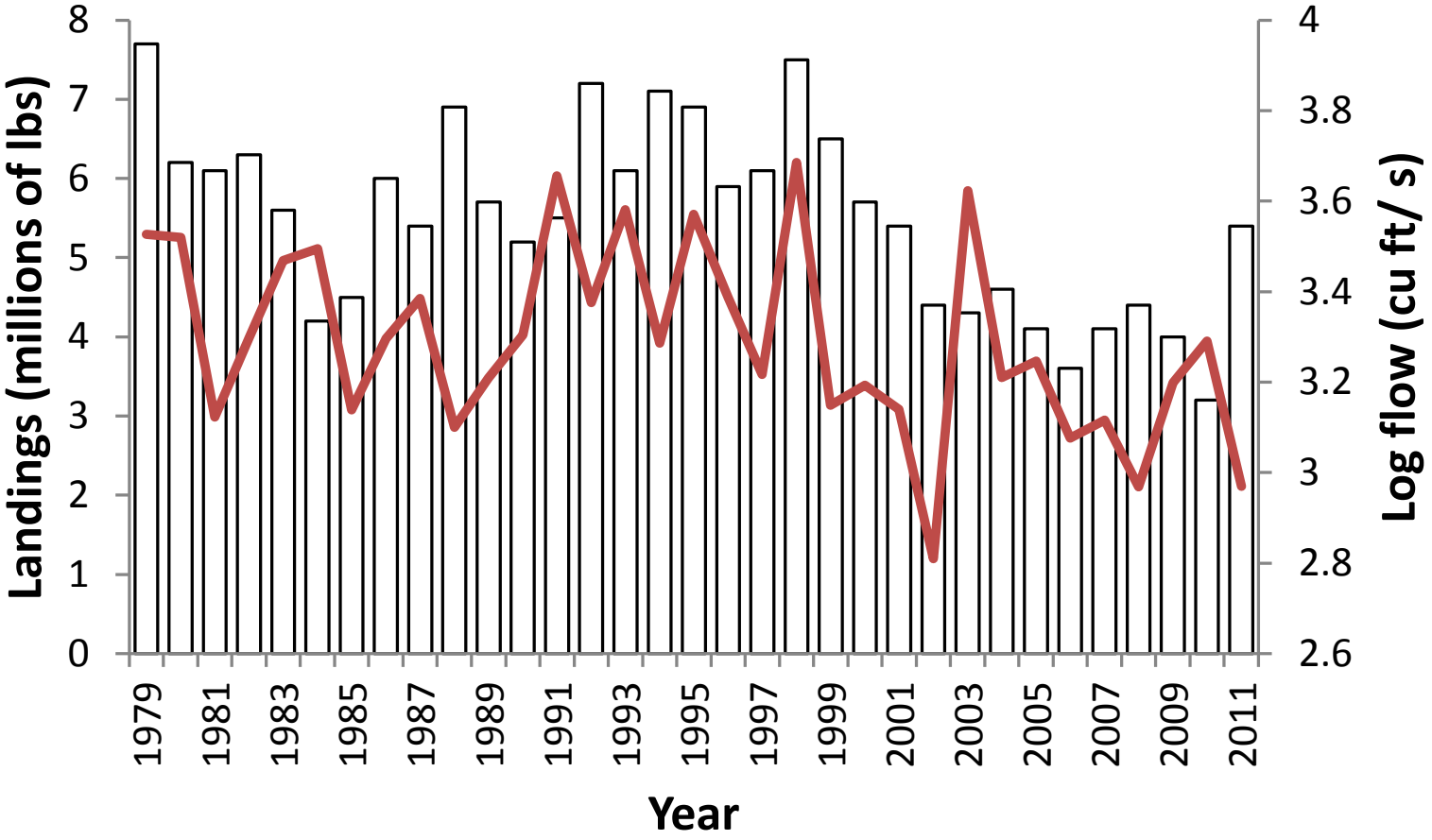
http://www.tpwd.state.tx.us/fishboat/fish/didyouknow/bluecrabdecline.phtml

Chesapeake Bay



http://www.washingtonpost.com/wp-dyn/content/graphic/2007/11/17/GR2007111700114.html?sid=ST2008041502012

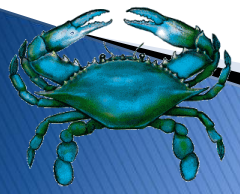
Why are blue crabs declining?



$r^2 = 0.109$, $p = 0.0340$

Presentation Outline

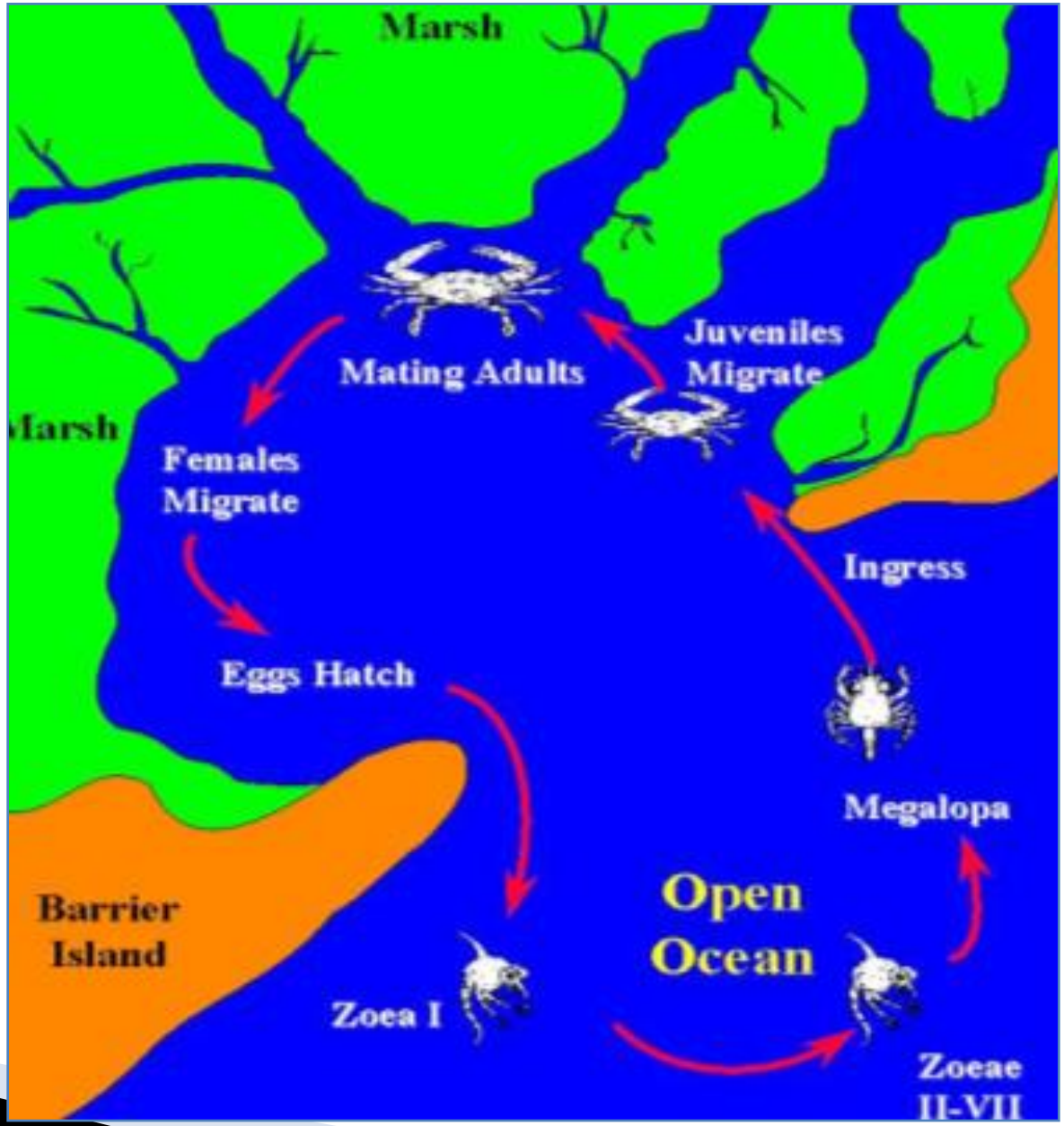
- Identification of the Problem – Dying of Thirst
- **Crab Life History – Why Salinity Matters**
- ACE Basin National Estuarine Research Reserve
- Patterns of Water Quality in Relation to Inflow
- Hypotheses Linking Crab Decline and Drought
- Forecasting the Future
- What Can Management Do?



Blue Crab

Callinectes sapidus

- Settlement = high salinity
- Maturation = low salinity
- Mating = low salinity
- Spawning = high salinity

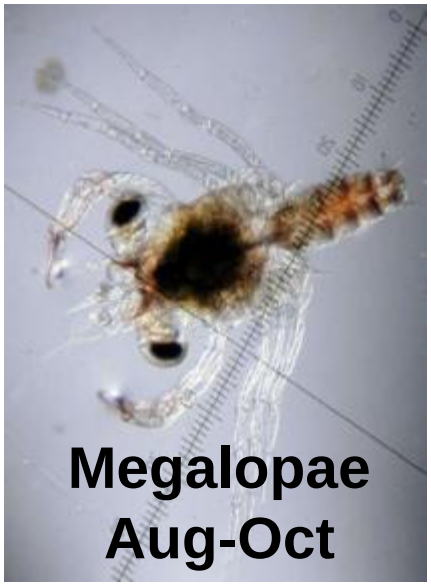



Mating
March-May


Egg incubation
April-June


Larval release
June-Aug

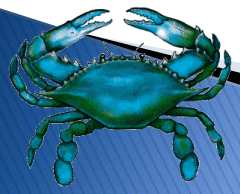

Zoeae
July-Sept

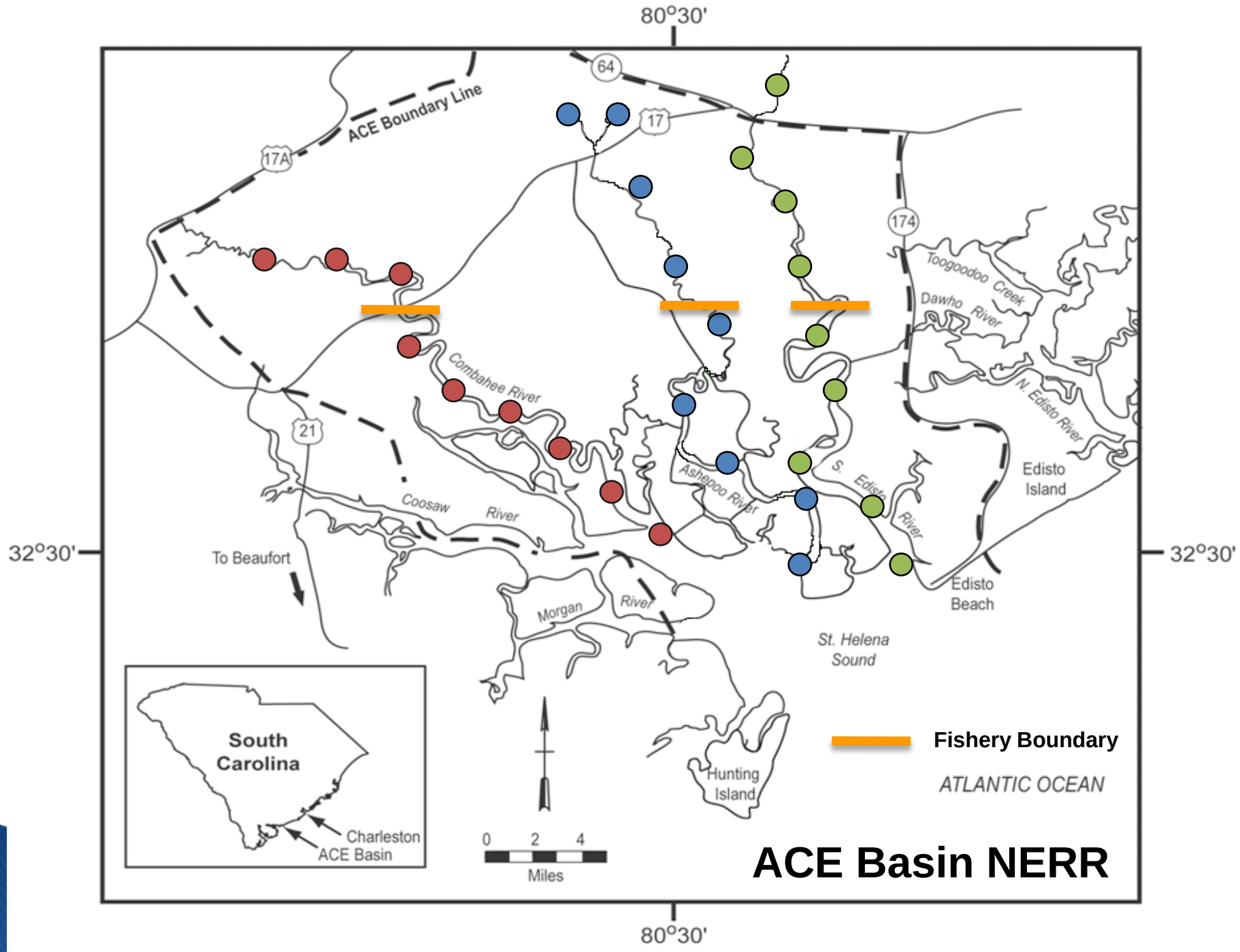

Megalopae
Aug-Oct


Juveniles
Sept-March (19 mo)

Presentation Outline

- Identification of the Problem – Dying of Thirst
- Crab Life History – Why Salinity Matters
- **ACE Basin National Estuarine Research Reserve**
- Patterns of Water Quality in Relation to Inflow
- Hypotheses Linking Crab Decline and Drought
- Forecasting the Future
- What Can Management Do?




80°30'
64
17
17A
ACE Boundary Line
174
Toogoodoo Creek
Dawho River
N. Edisto River
Edisto Island
S. Edisto River
Edisto Beach
Combahee River
21
Coosaw River
Ashepoo River
To Beaufort
Morgan River
St. Helena Sound
Hunting Island
32°30'
32°30'
80°30'
South Carolina
Charleston
ACE Basin
0 2 4
Miles
Fishery Boundary
ATLANTIC OCEAN
ACE Basin NERR


Water Quality

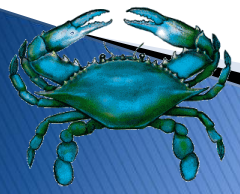

Crab Density

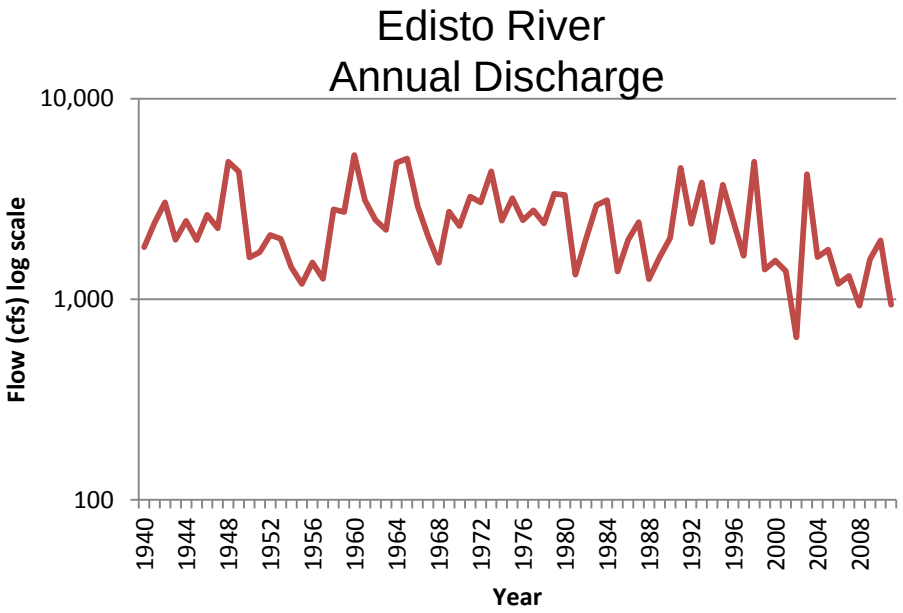

0806-COM1-13-002
Size, Sex, Maturity

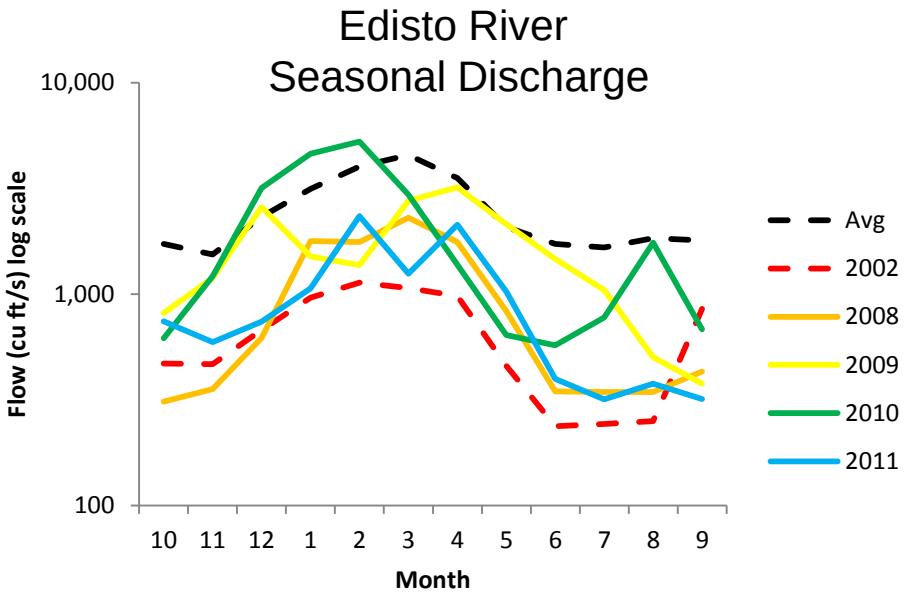

Disease

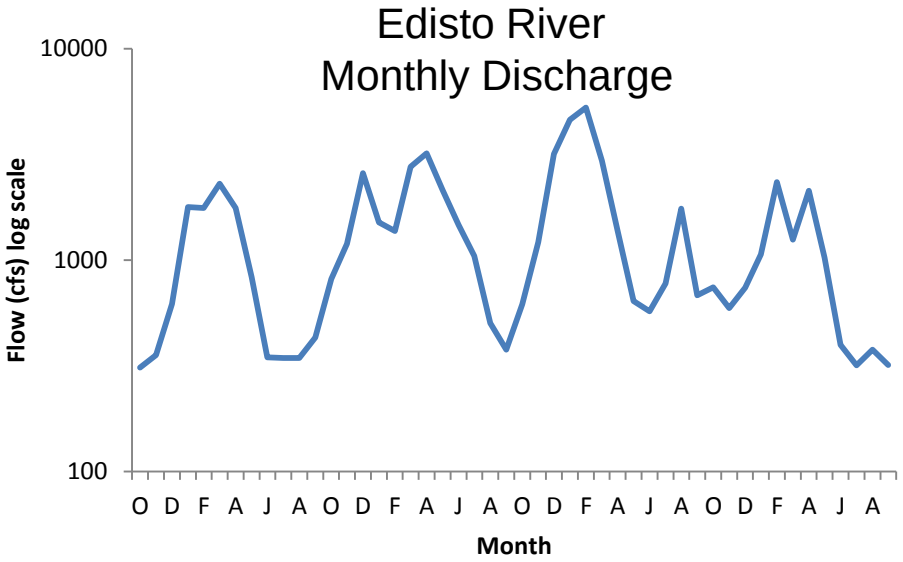
Presentation Outline

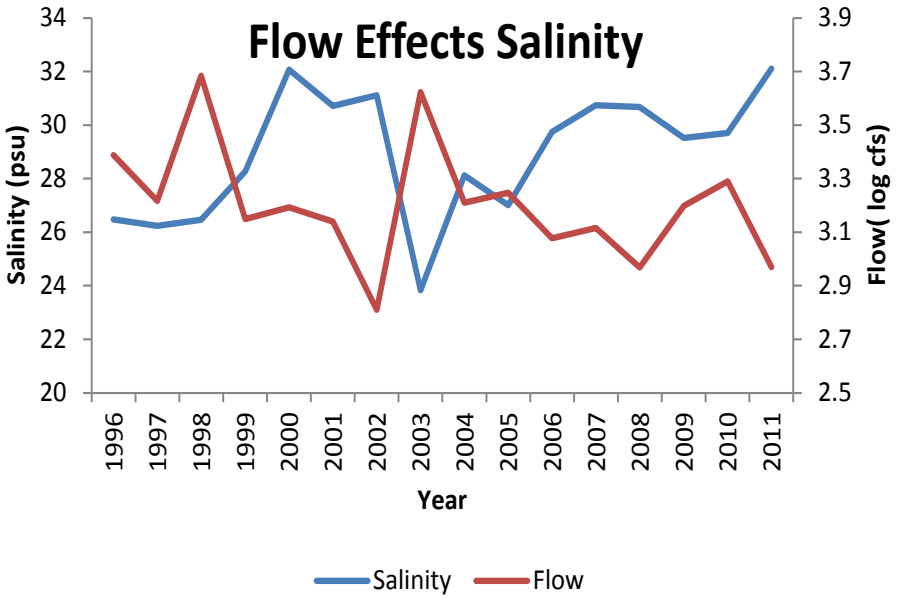
- Identification of the Problem – Dying of Thirst
- Crab Life History – Why Salinity Matters
- ACE Basin National Estuarine Research Reserve
- **Patterns of Water Quality in Relation to Inflow**
- Hypotheses Linking Crab Decline and Drought
- Forecasting the Future
- What Can Management Do?



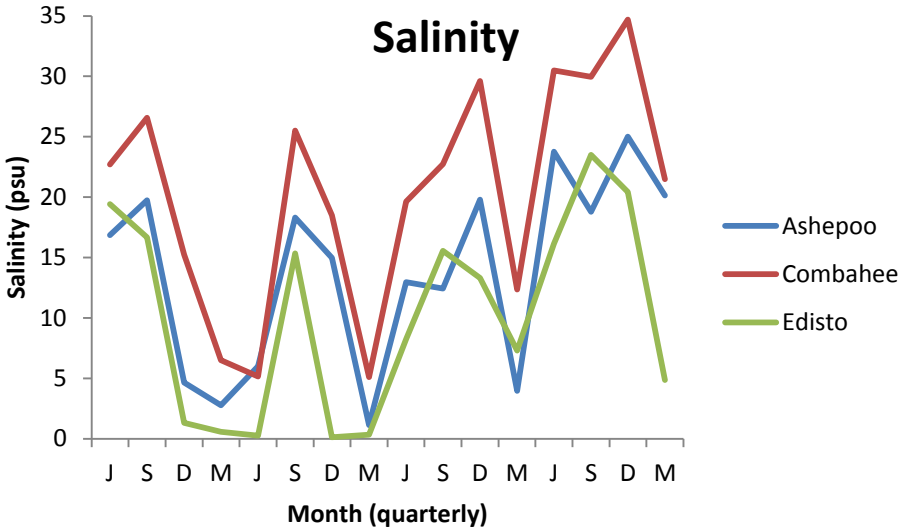




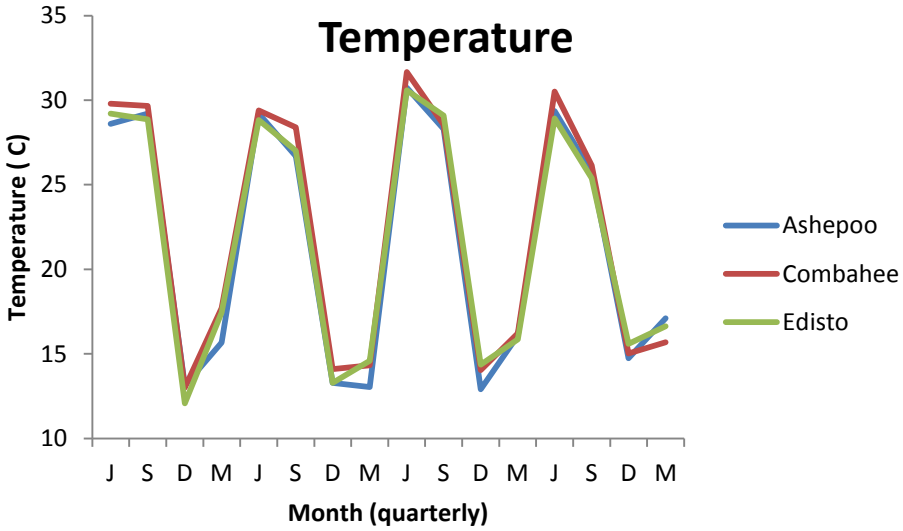




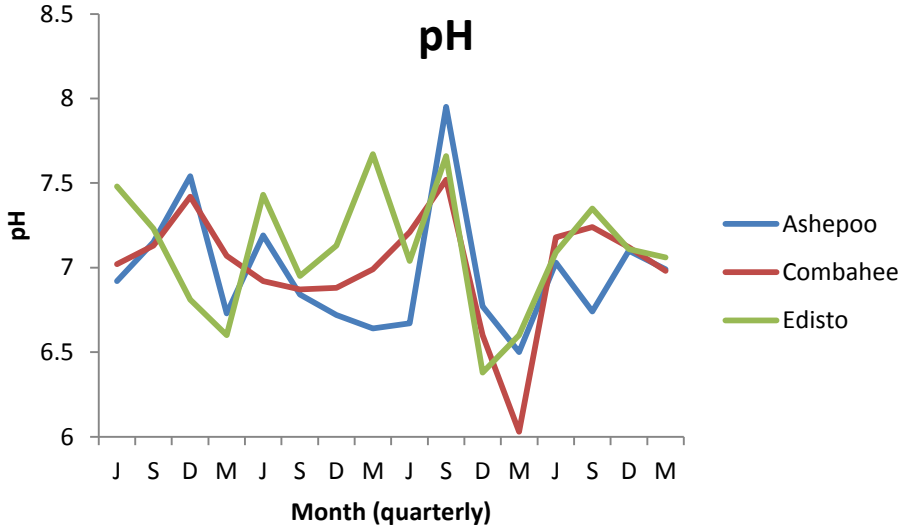
USGS 02175000 – Givhans Ferry, SC



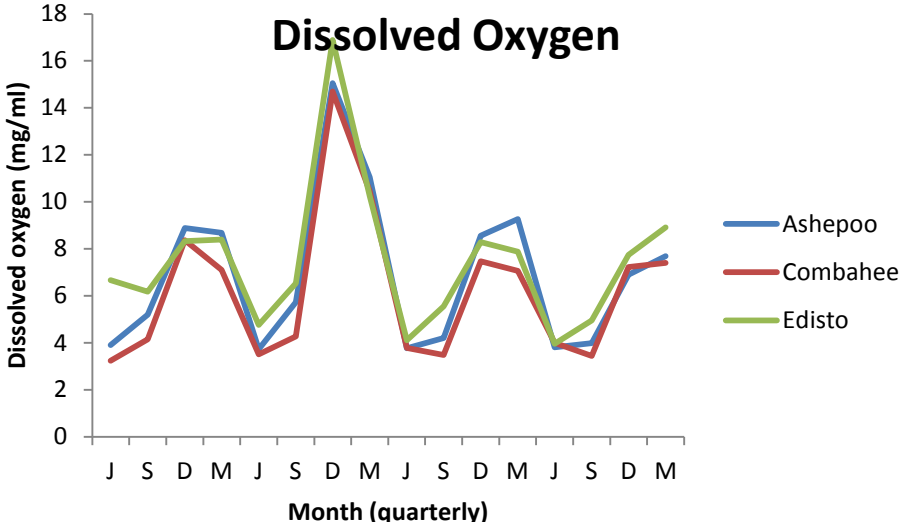
$r^2 = 0.607$, $p = 0.0001$



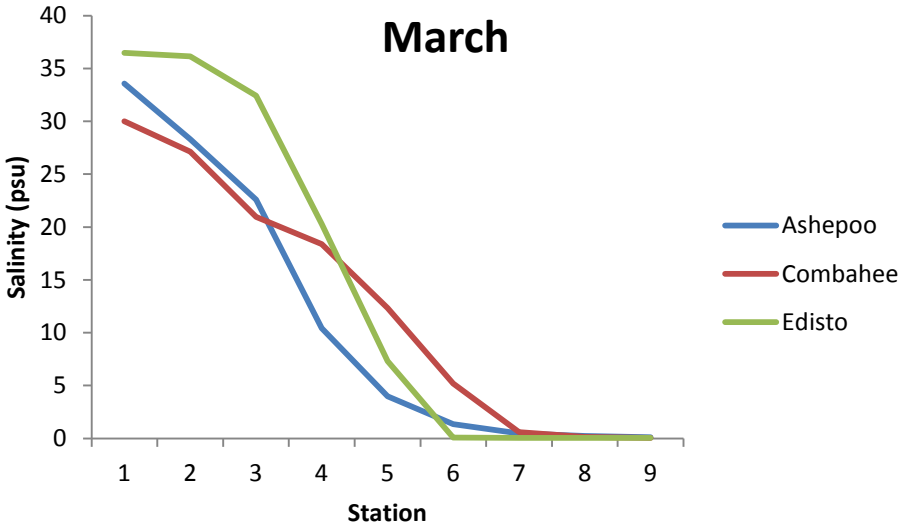
$r^2 = 0.059$, $p = 0.7497$

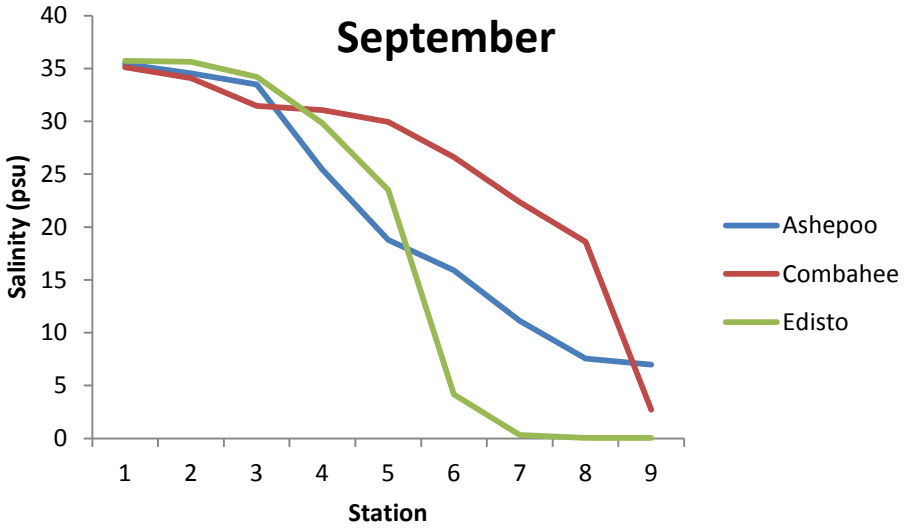


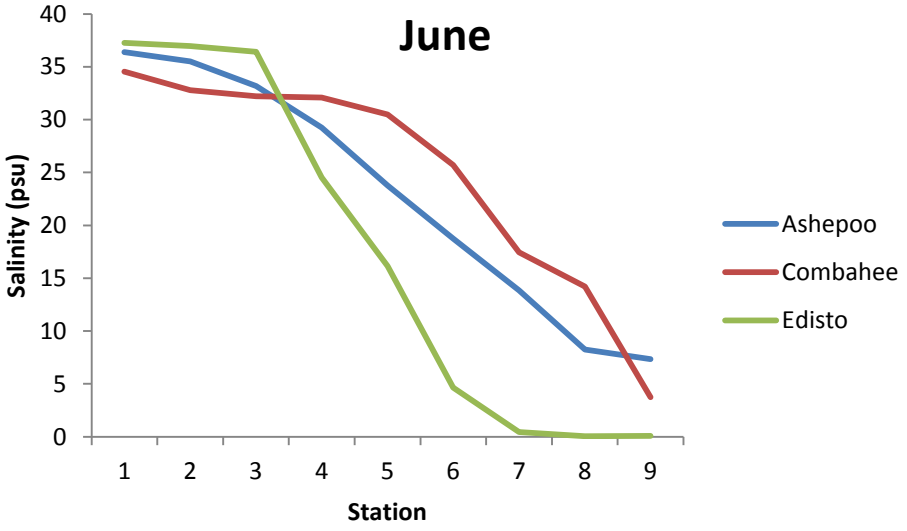
$r^2 = 0.064$, $p = 0.8412$

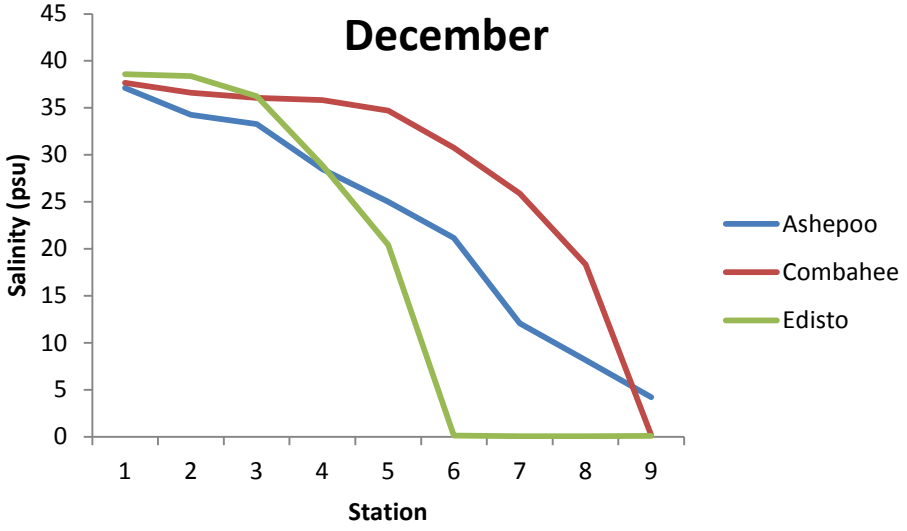


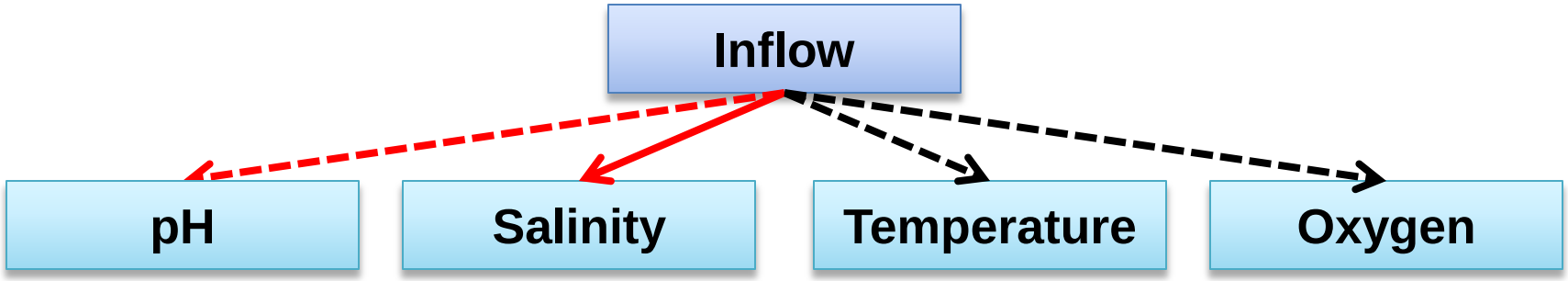
$r^2 = 0.006$, $p = 0.3578$


March
Salinity (psu)
40
35
30
25
20
15
10
5
0
1 2 3 4 5 6 7 8 9
Station
Ashepoo
Combahee
Edisto


September
Salinity (psu)
40
35
30
25
20
15
10
5
0
1 2 3 4 5 6 7 8 9
Station
Ashepoo
Combahee
Edisto

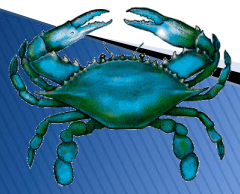

June
Salinity (psu)
40
35
30
25
20
15
10
5
0
1 2 3 4 5 6 7 8 9
Station
Ashepoo
Combahee
Edisto


December
Salinity (psu)
45
40
35
30
25
20
15
10
5
0
1 2 3 4 5 6 7 8 9
Station
Ashepoo
Combahee
Edisto


Inflow
pH
Salinity
Temperature
Oxygen

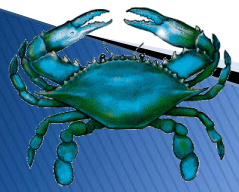
Presentation Outline

- Identification of the Problem – Dying of Thirst
- Crab Life History – Why Salinity Matters
- ACE Basin National Estuarine Research Reserve
- Patterns of Water Quality in Relation to Inflow
- **Hypotheses Linking Crab Decline and Drought**
- Forecasting the Future
- What Can Management Do?



Hypotheses linking crab decline and drought

- Higher salinity increases fishing
- Higher salinity increases disease
- Higher salinity decreases settlement
- Higher salinity increases predation

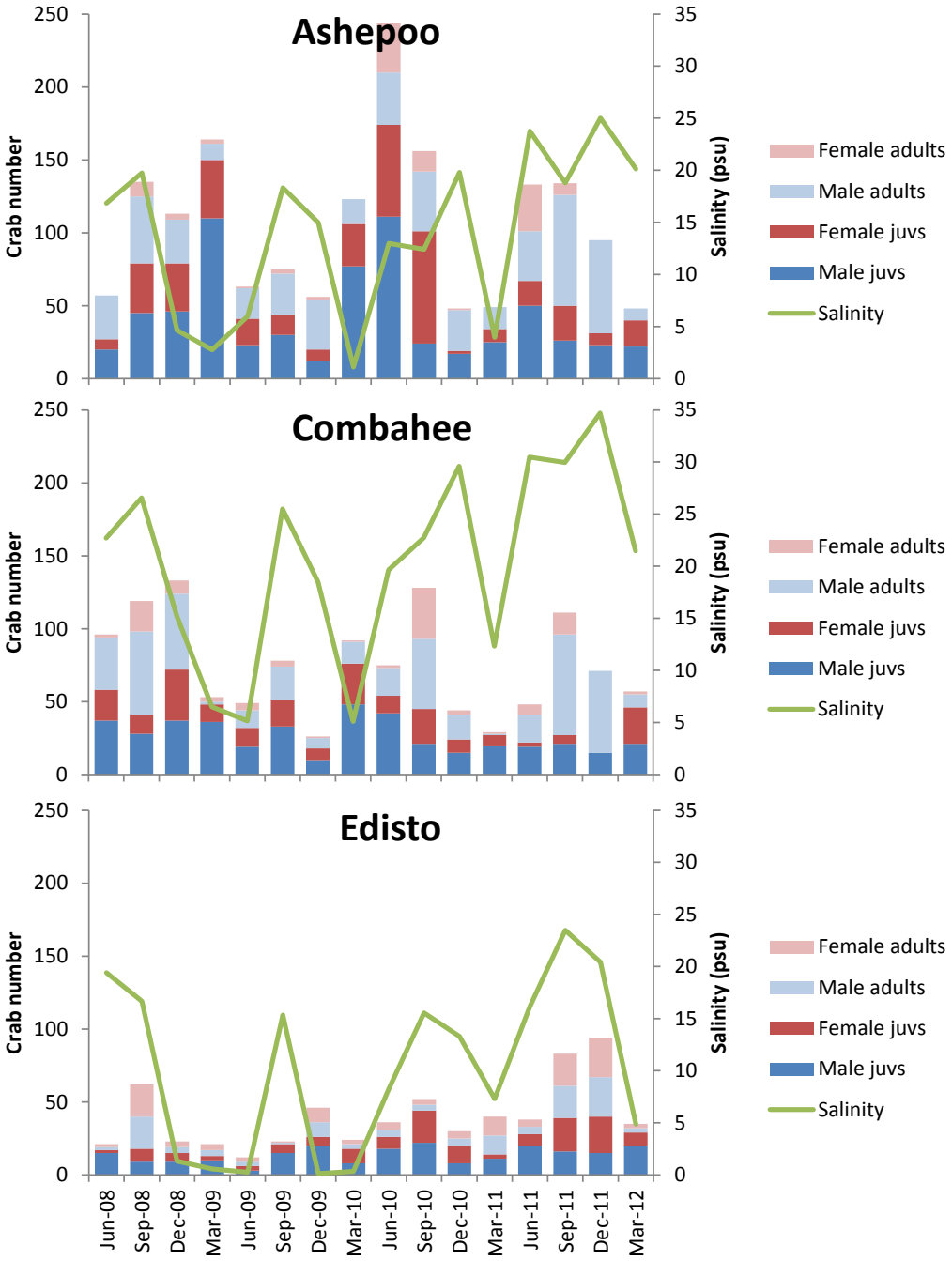



Fishing


Disease


Settlement


Predation



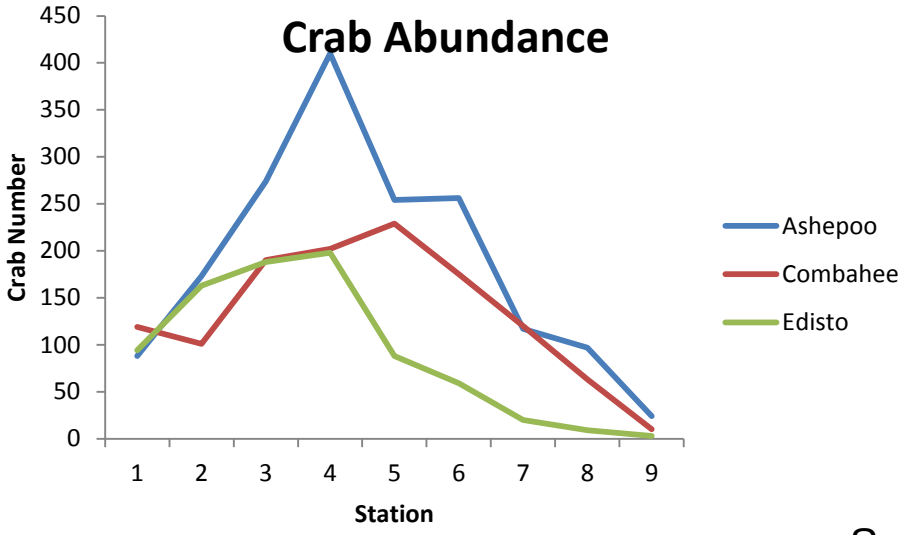
Female adults
$r^2 = 0.033$, $p = 0.2159$

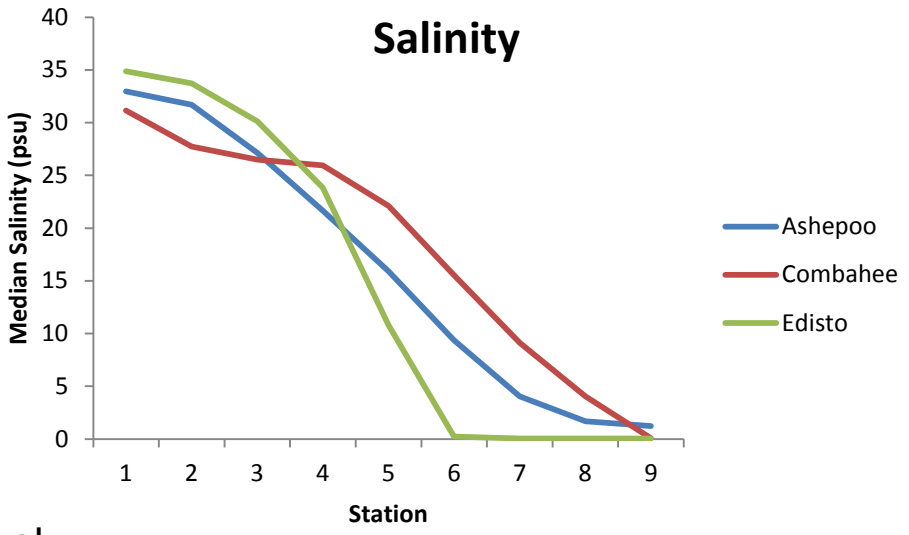
Male adults
$r^2 = 0.308$, $p = 0.0001$

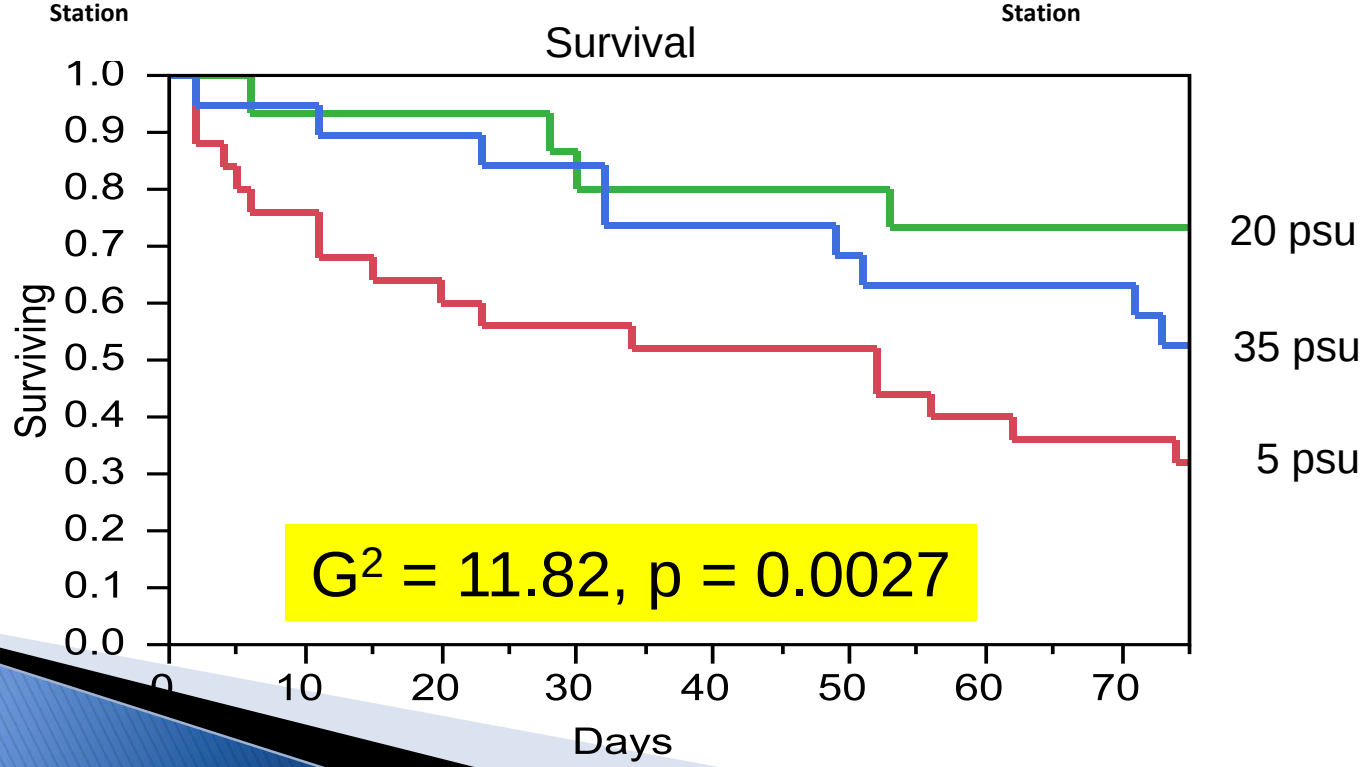
Female juveniles
$r^2 = 0.059$, $p = 0.0971$

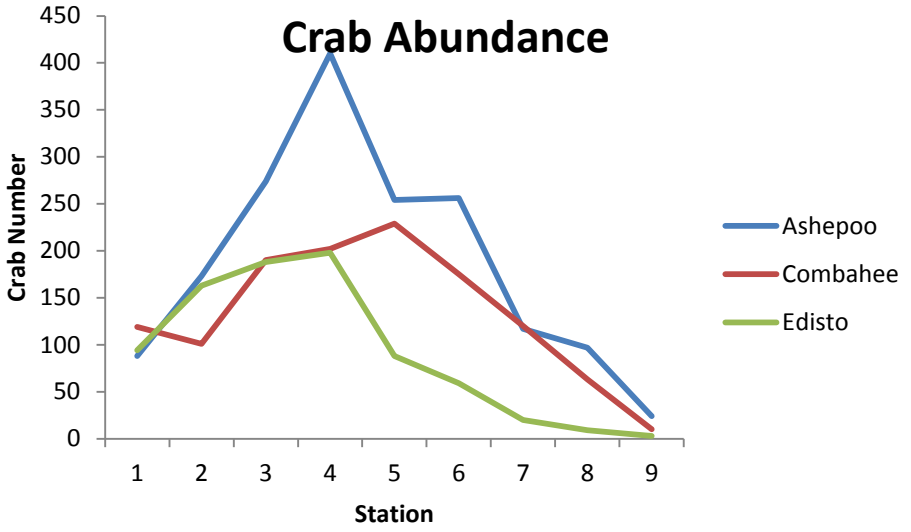
Male juveniles
$r^2 = 0.000$, $p = 0.9071$

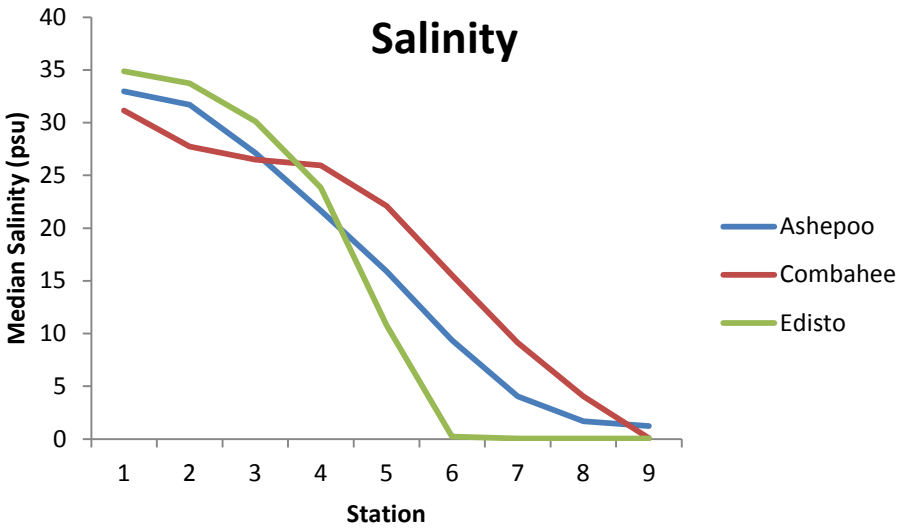
All crabs
$r^2 = 0.058$, $p = 0.0988$

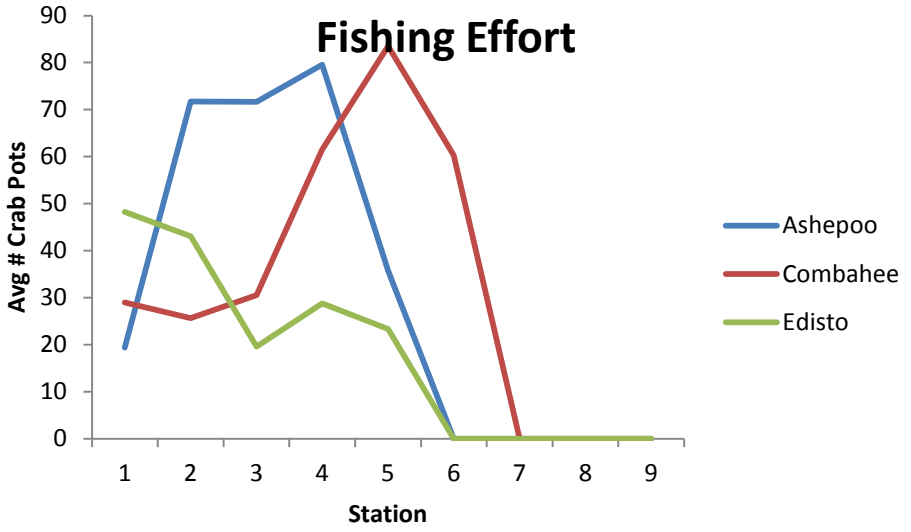

Crab Abundance
Crab Number
450
400
350
300
250
200
150
100
50
0
1
2
3
4
5
6
7
8
9
Station
Ashepoo
Combahee
Edisto

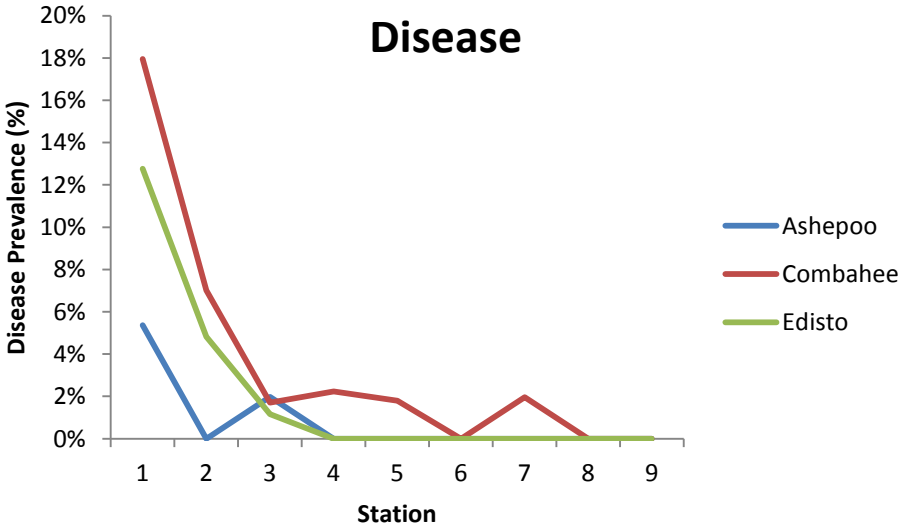

Salinity
Median Salinity (psu)
40
35
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
Station
Ashepoo
Combahee
Edisto


Survival
Surviving
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0
10
20
30
40
50
60
70
Days
20 psu
35 psu
5 psu
G² = 11.82, p = 0.0027







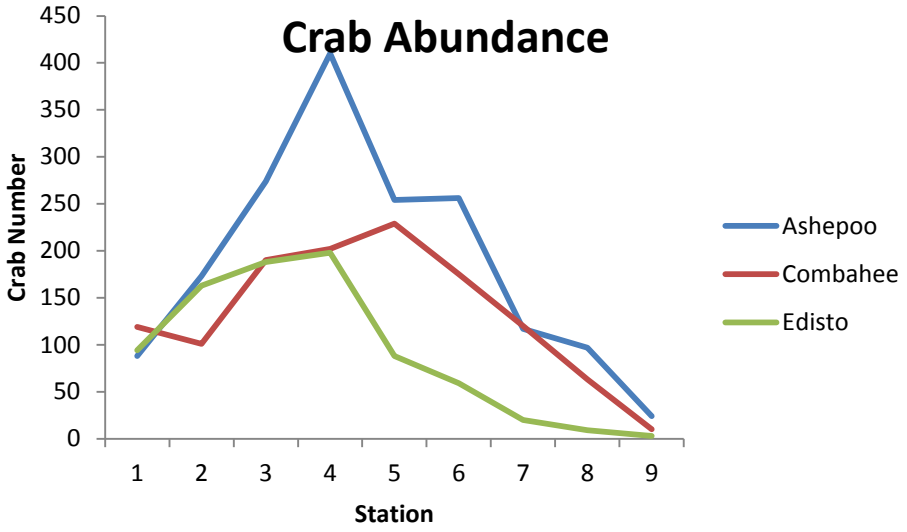


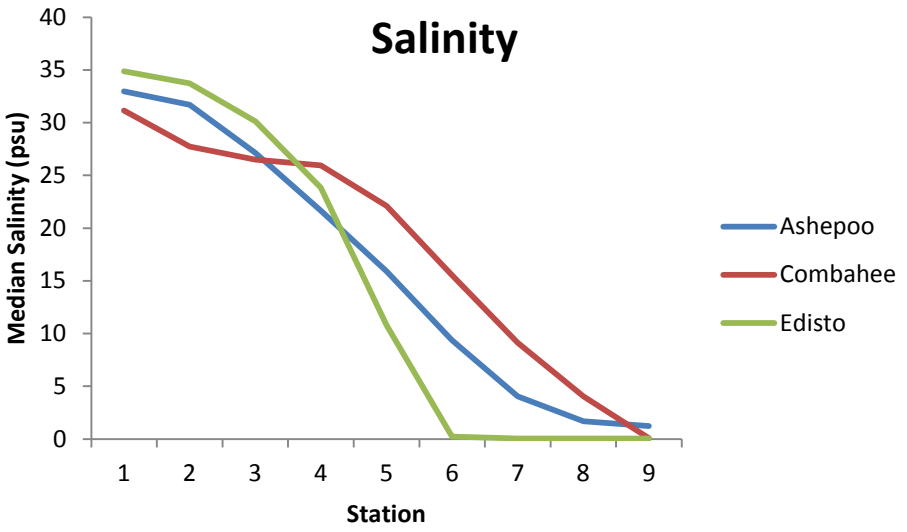
Crabs: $r^2 = 0.084$, $p = 0.0454$

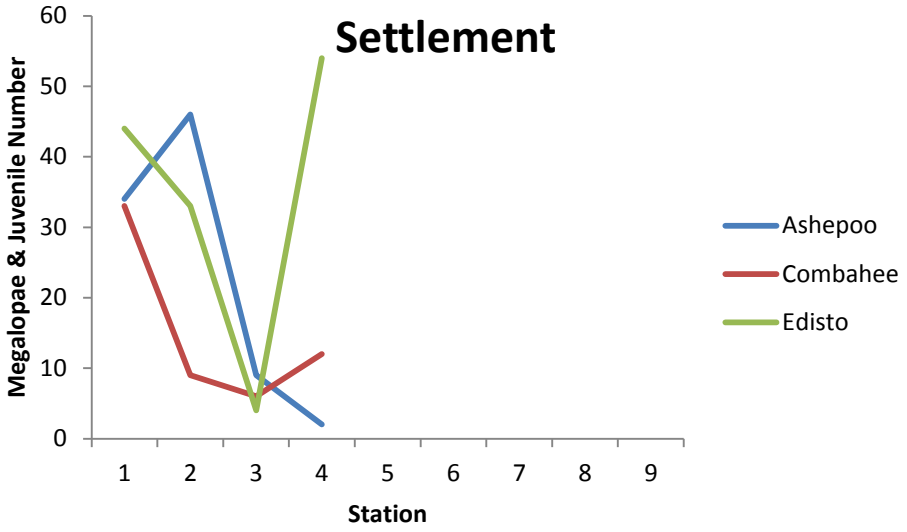
Salinity: $r^2 = 0.035$, $p = 0.2057$

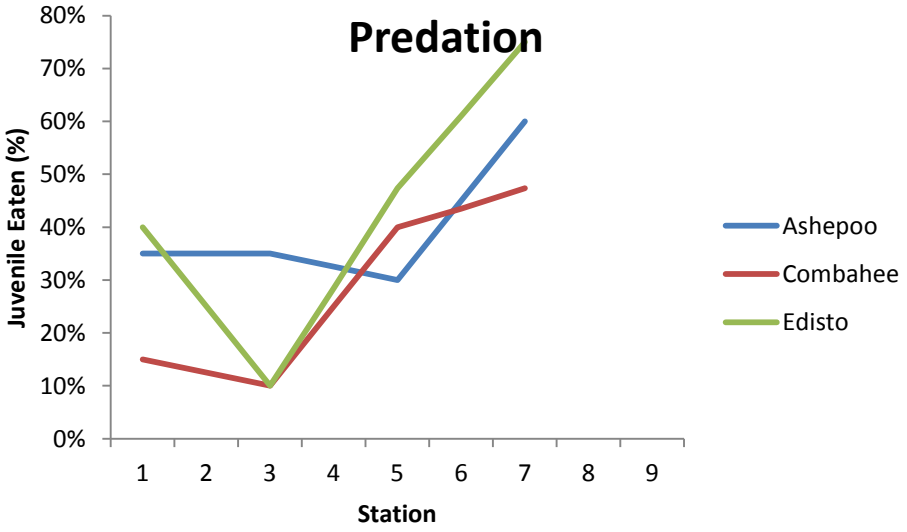
Crabs: $r^2 = 0.008$, $p = 0.5298$

Salinity: $r^2 = 0.277$, $p = 0.0786$







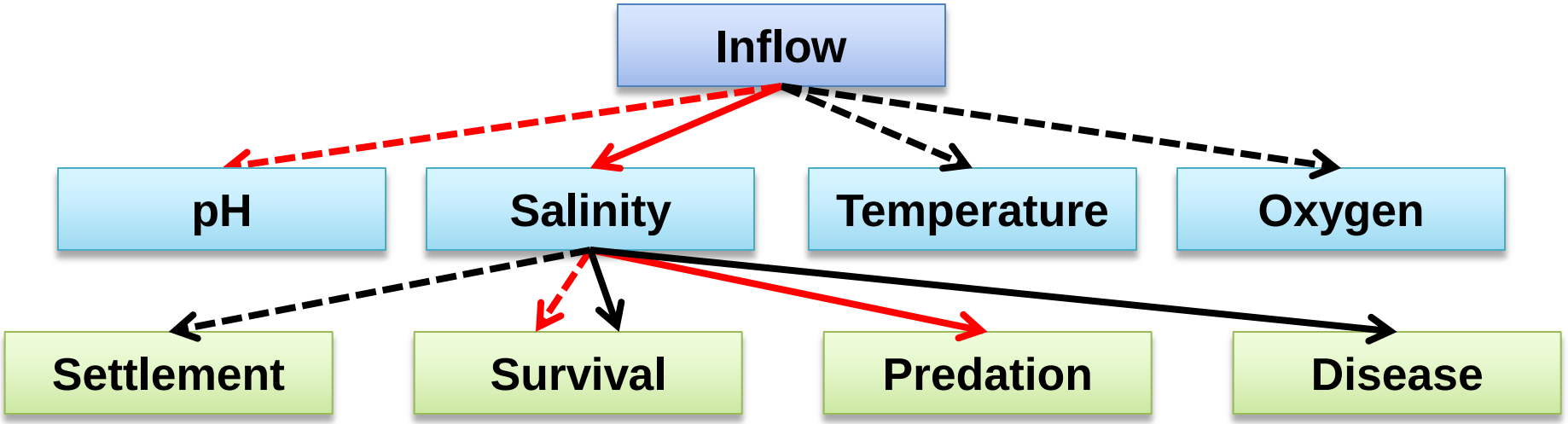


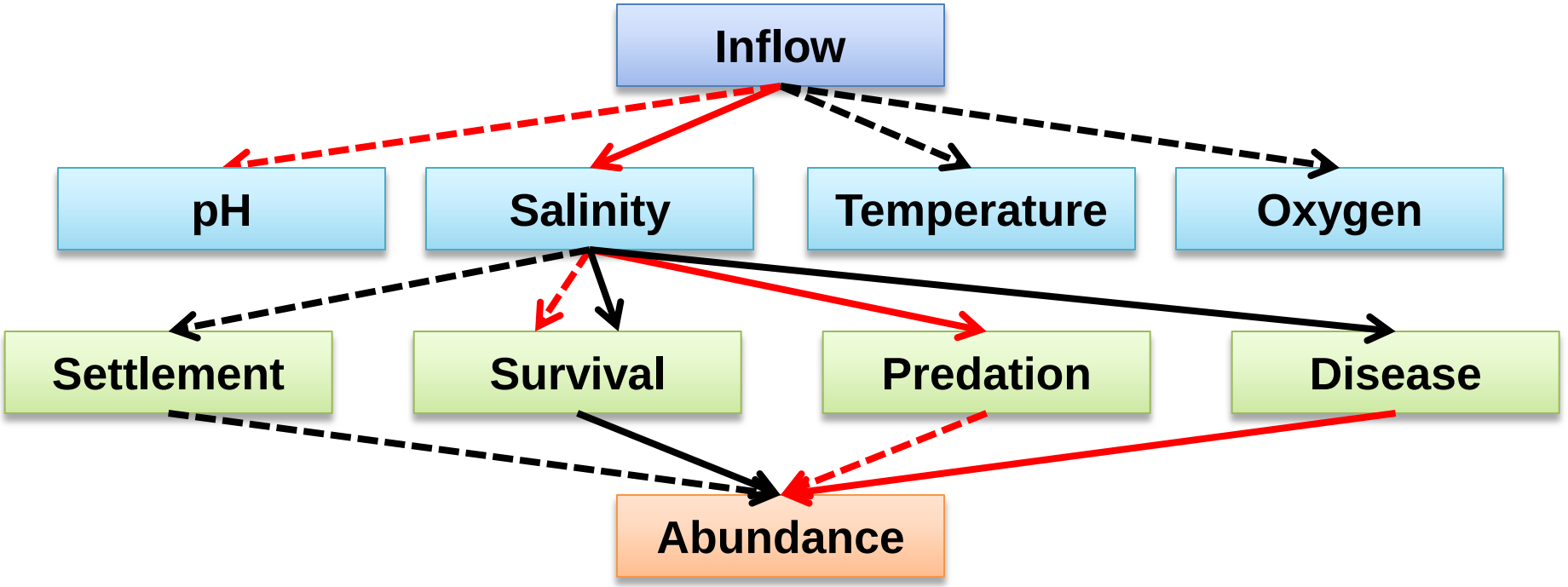
Crabs: $r^2 = 0.240$, $p = 0.3225$

Salinity: $r^2 = 0.051$, $p = 0.1720$

Crabs: $r^2 = 0.040$, $p = 0.5389$

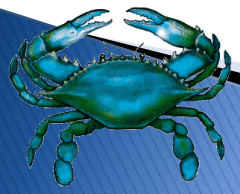
Salinity: $r^2 = 0.743$, $p = 0.0003$

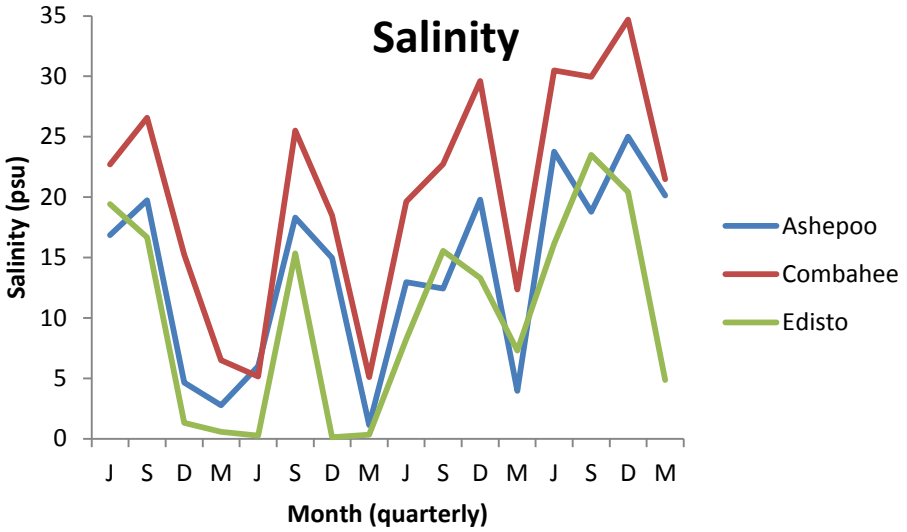

Inflow
pH
Salinity
Temperature
Oxygen
Settlement
Survival
Predation
Disease

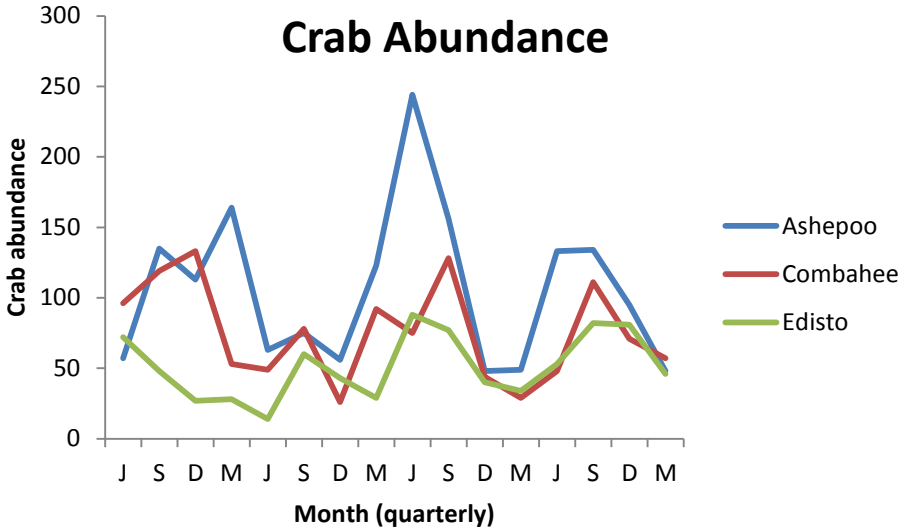

Inflow
pH
Salinity
Temperature
Oxygen
Settlement
Survival
Predation
Disease
Abundance

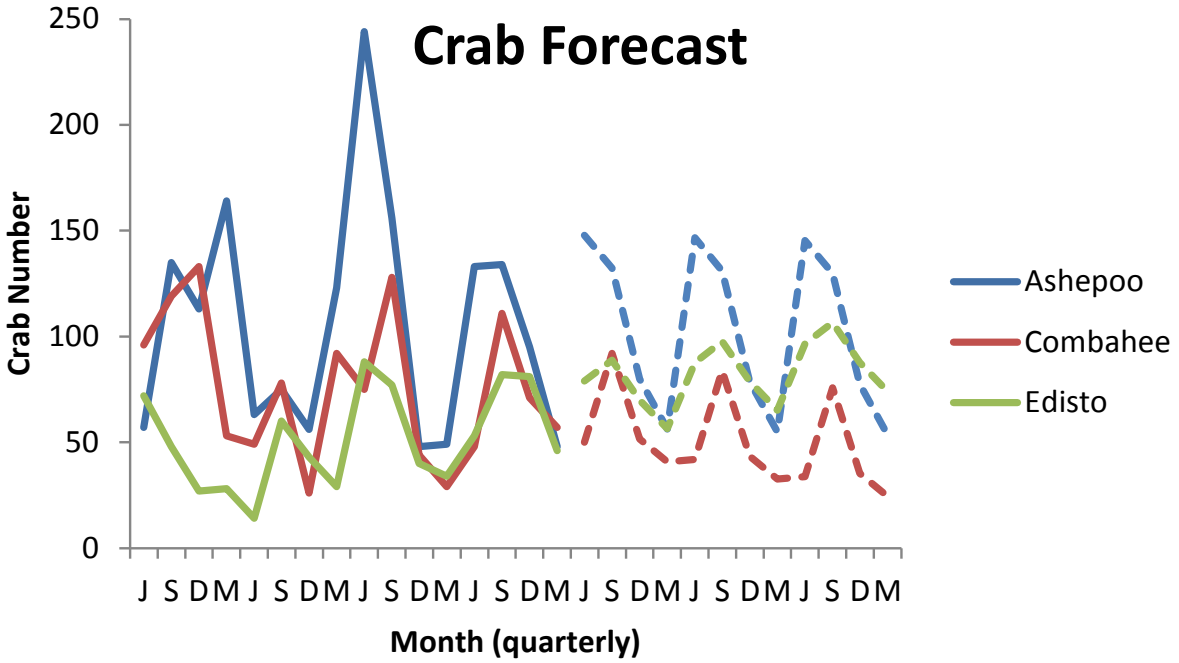
Presentation Outline

- Identification of the Problem – Dying of Thirst
- Crab Life History – Why Salinity Matters
- ACE Basin National Estuarine Research Reserve
- Patterns of Water Quality in Relation to Inflow
- Hypotheses Linking Crab Decline and Drought
- **Forecasting the Future**
- What Can Management Do?

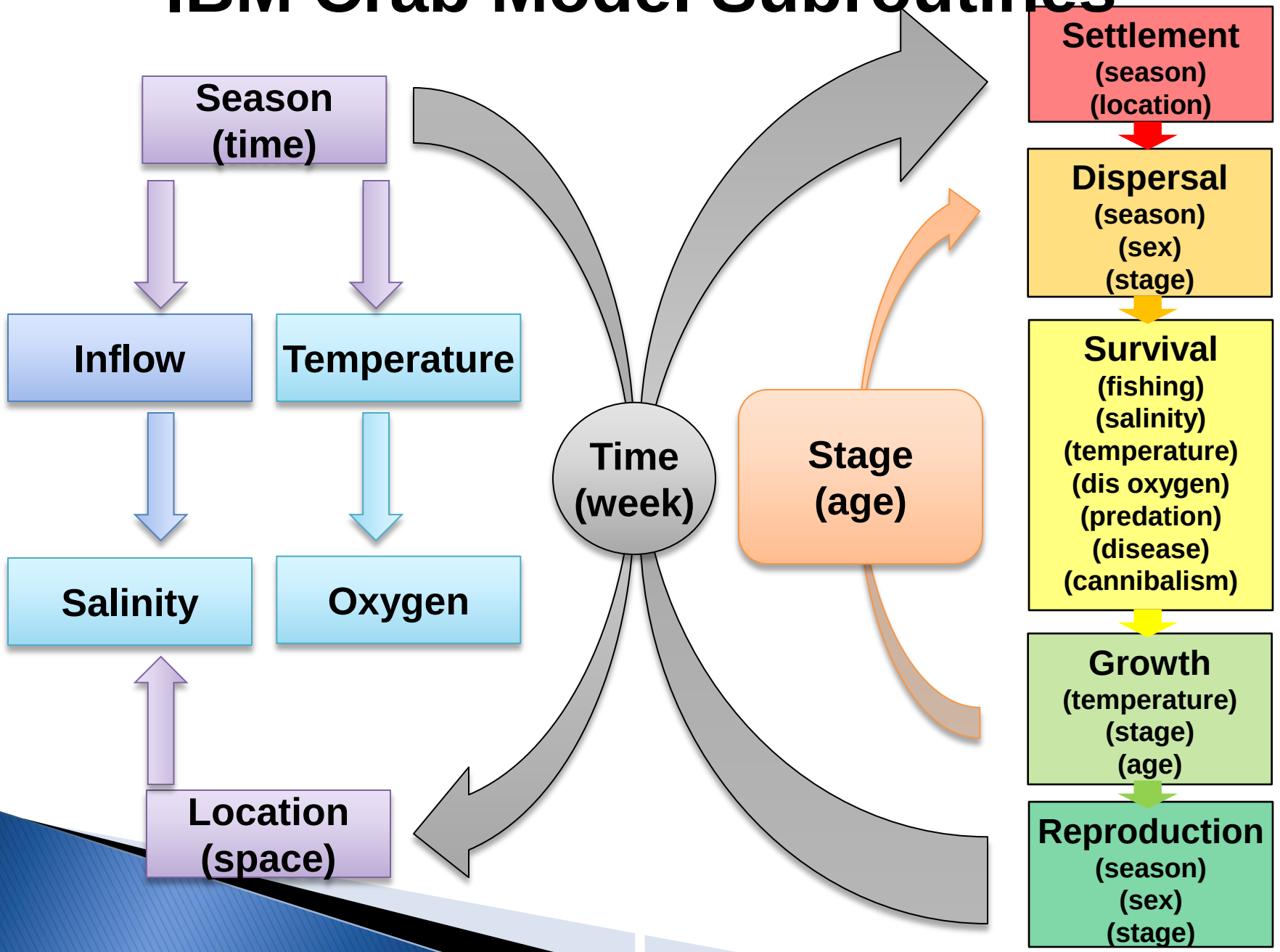



Salinity
Salinity (psu)
35
30
25
20
15
10
5
0
J S D M J S D M J S D M J S D M
Month (quarterly)
Ashepoo
Combahee
Edisto

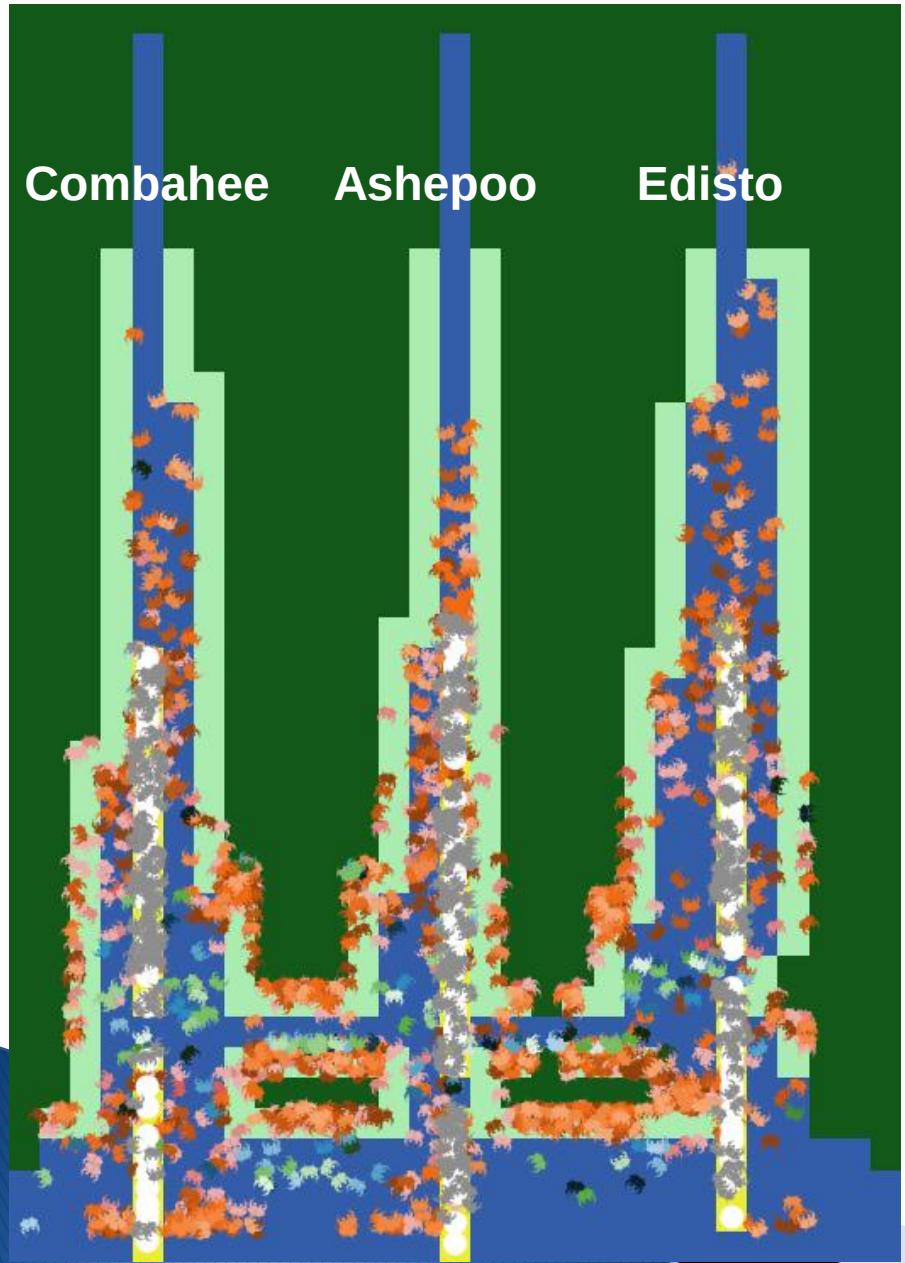

Crab Abundance
Crab abundance
300
250
200
150
100
50
0
J S D M J S D M J S D M J S D M
Month (quarterly)
Ashepoo
Combahee
Edisto

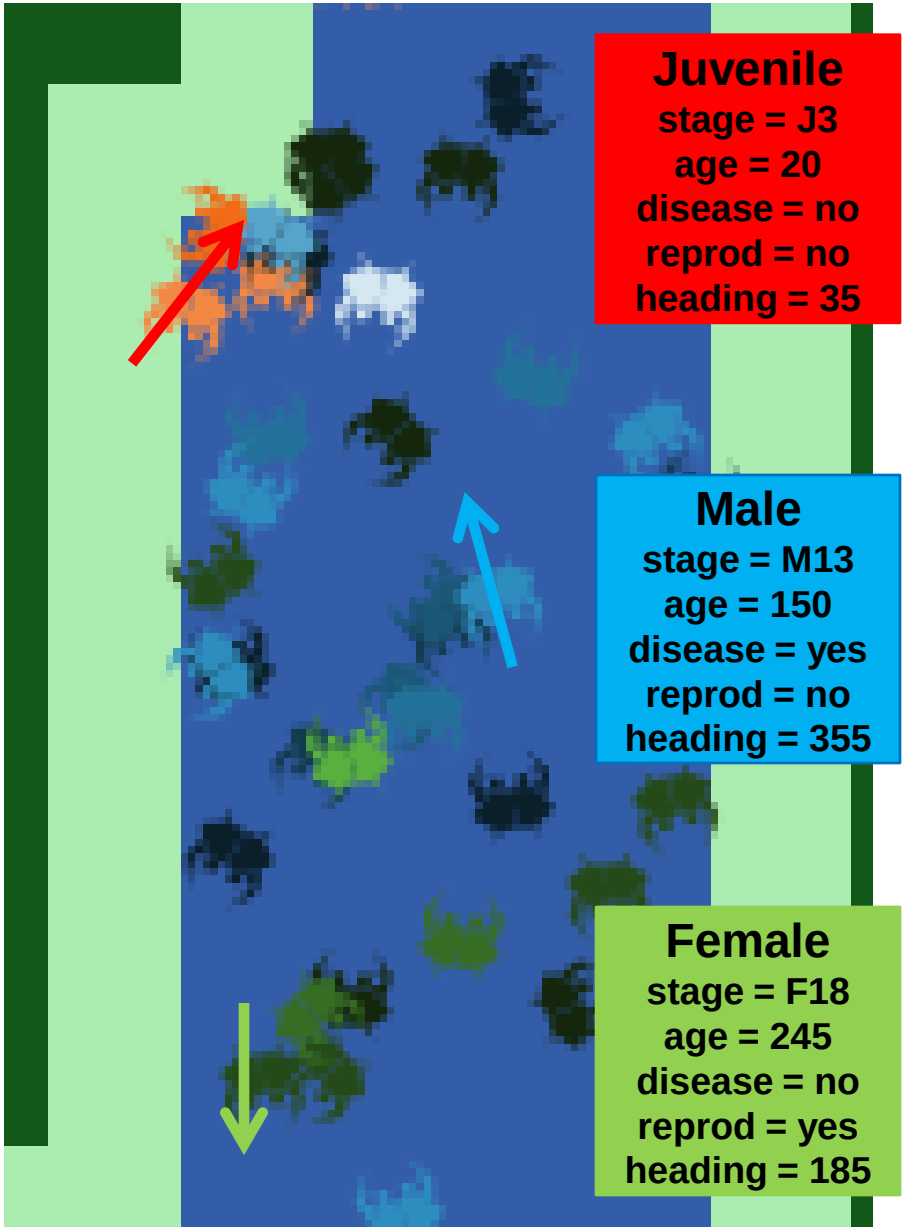

Crab Forecast
Crab Number
250
200
150
100
50
0
J S D M J S D M J S D M J S D M J S D M J S D M J S D M
Month (quarterly)
Ashepoo
Combahee
Edisto

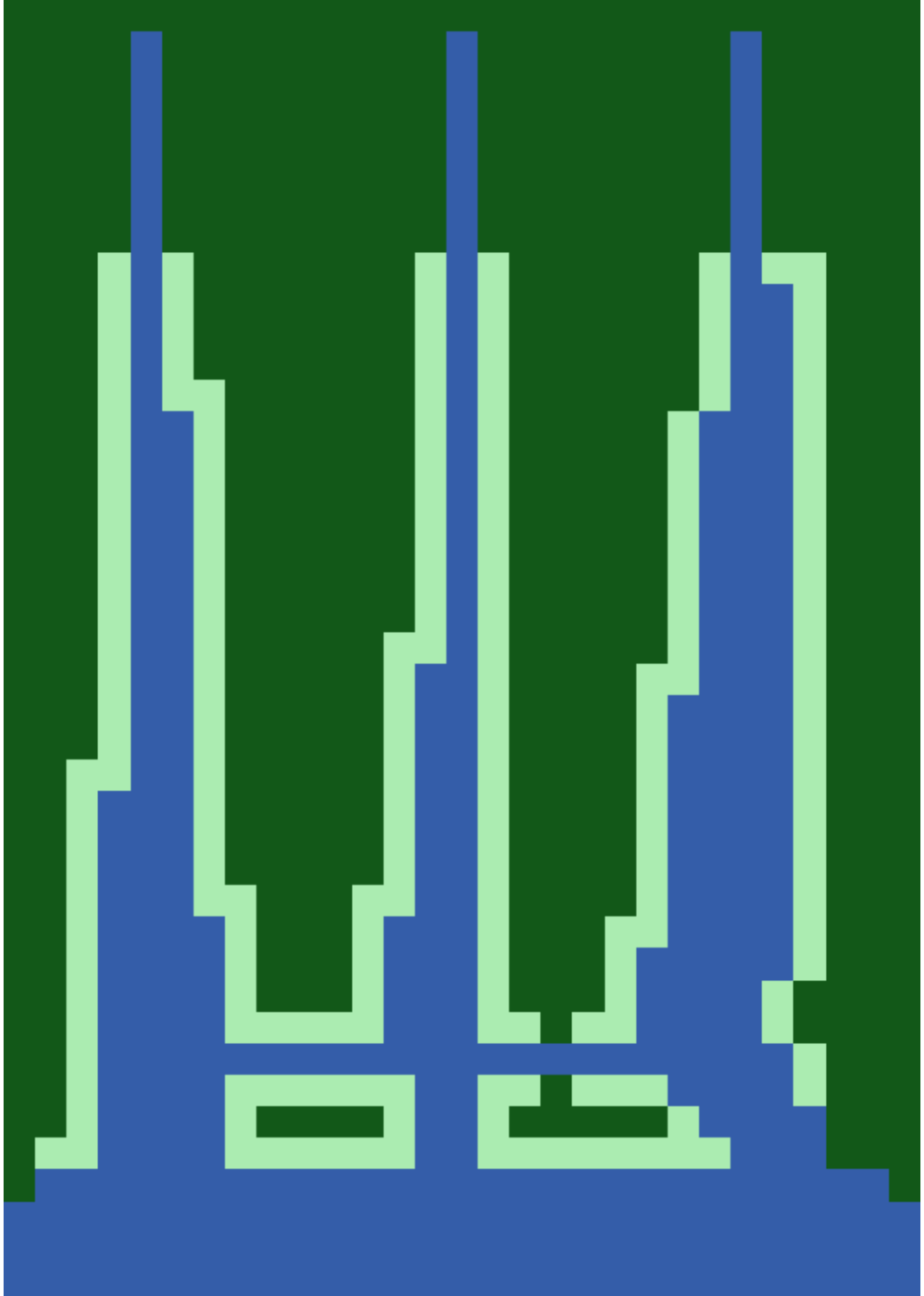
IBM Crab Model Subroutines

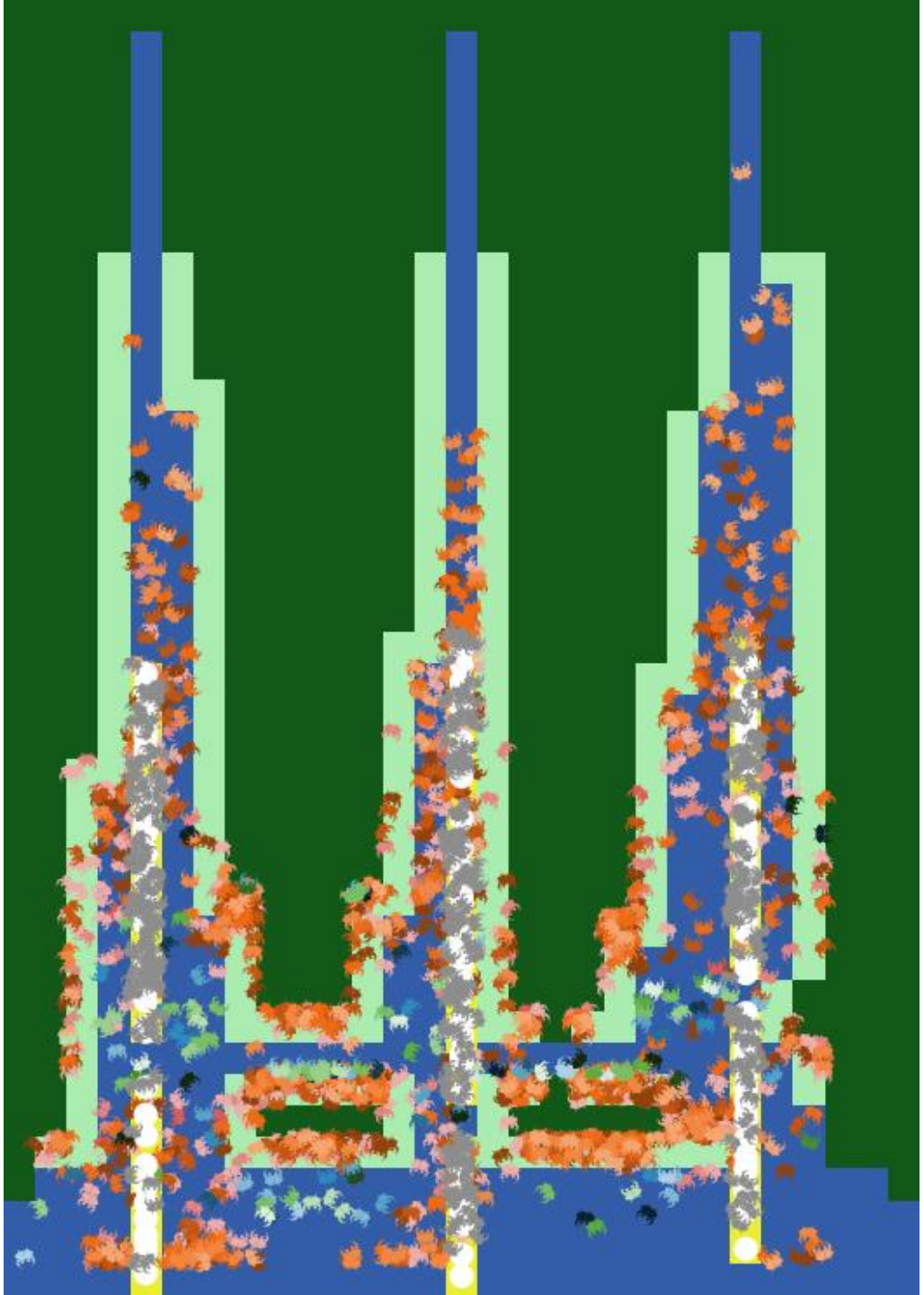


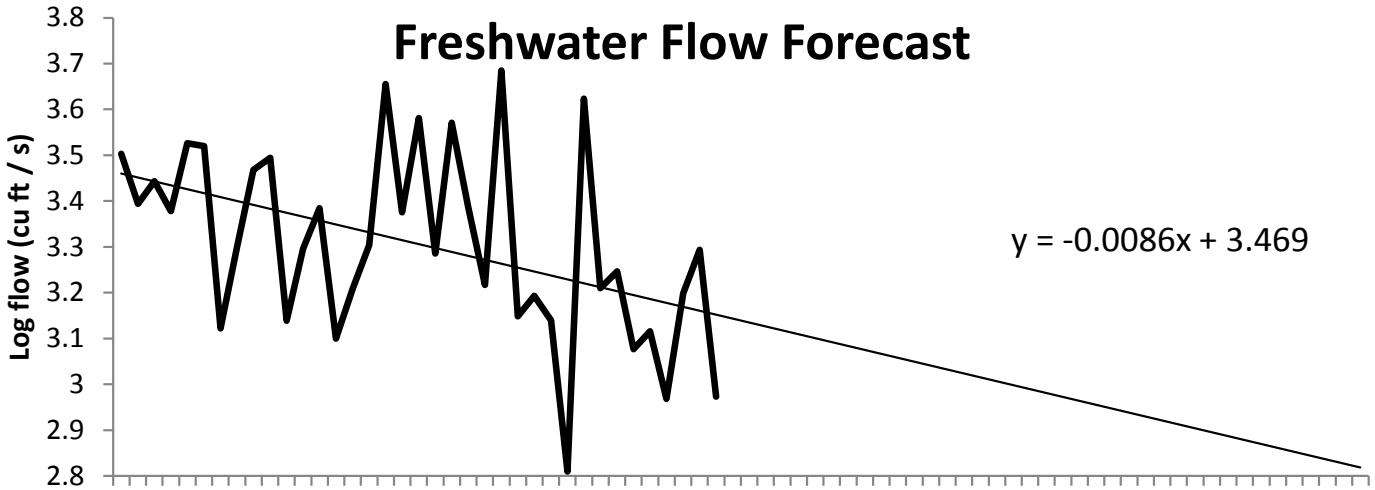
IBM Crab Model Spatial Structure

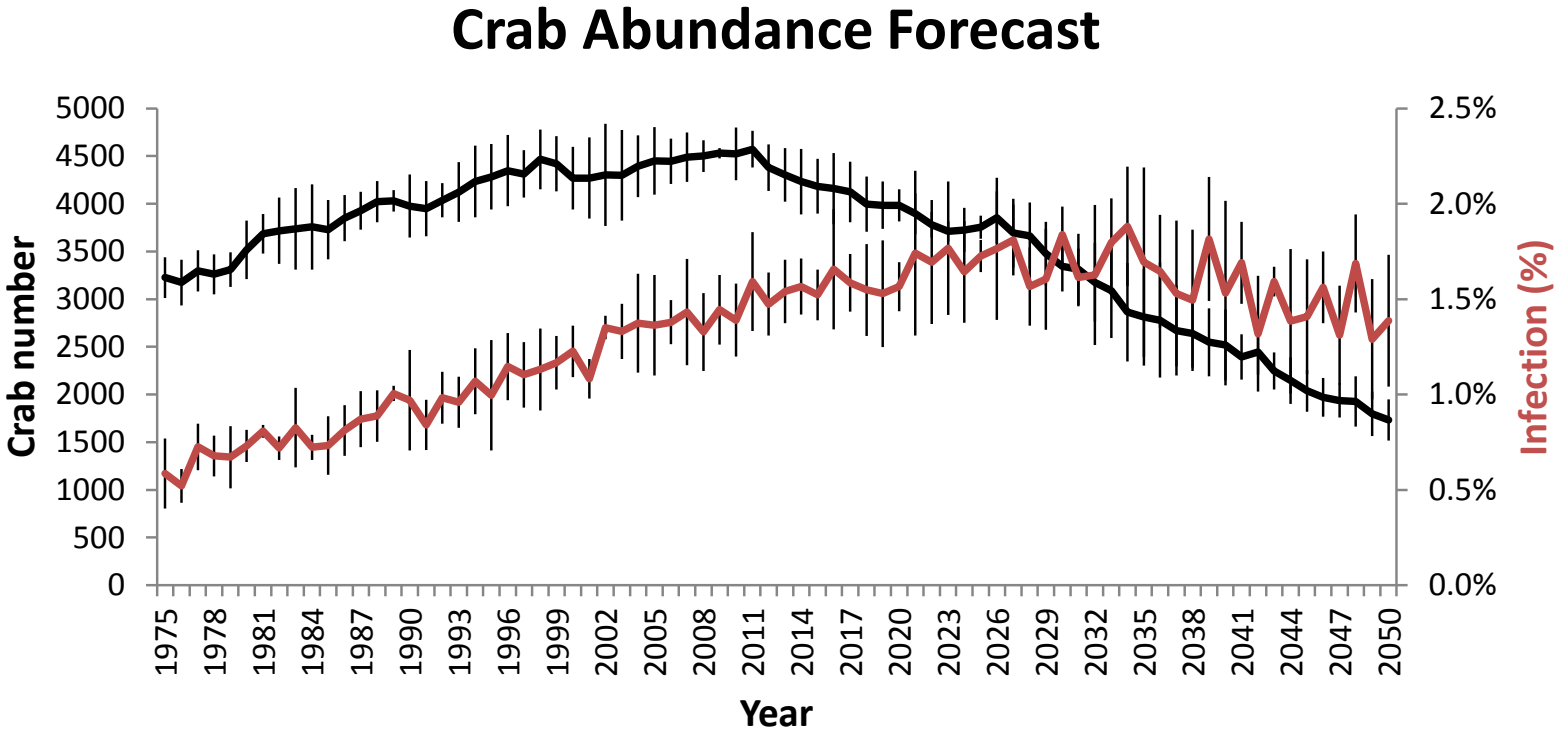


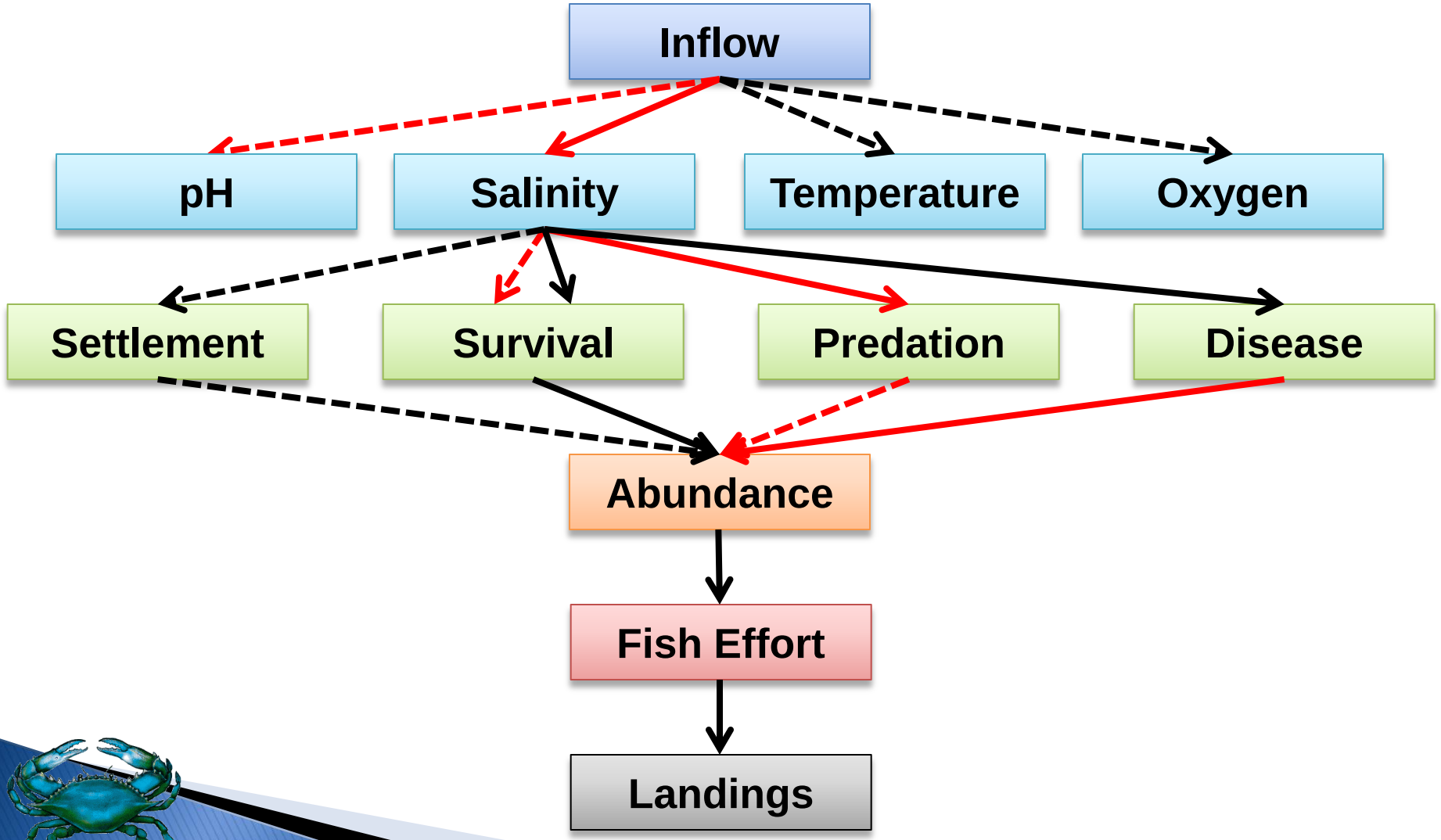






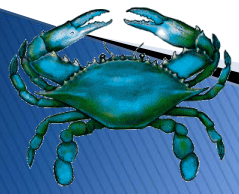

Freshwater Flow Forecast
Log flow (cu ft / s)
3.8
3.7
3.6
3.5
3.4
3.3
3.2
3.1
3
2.9
2.8
y = -0.0086x + 3.469

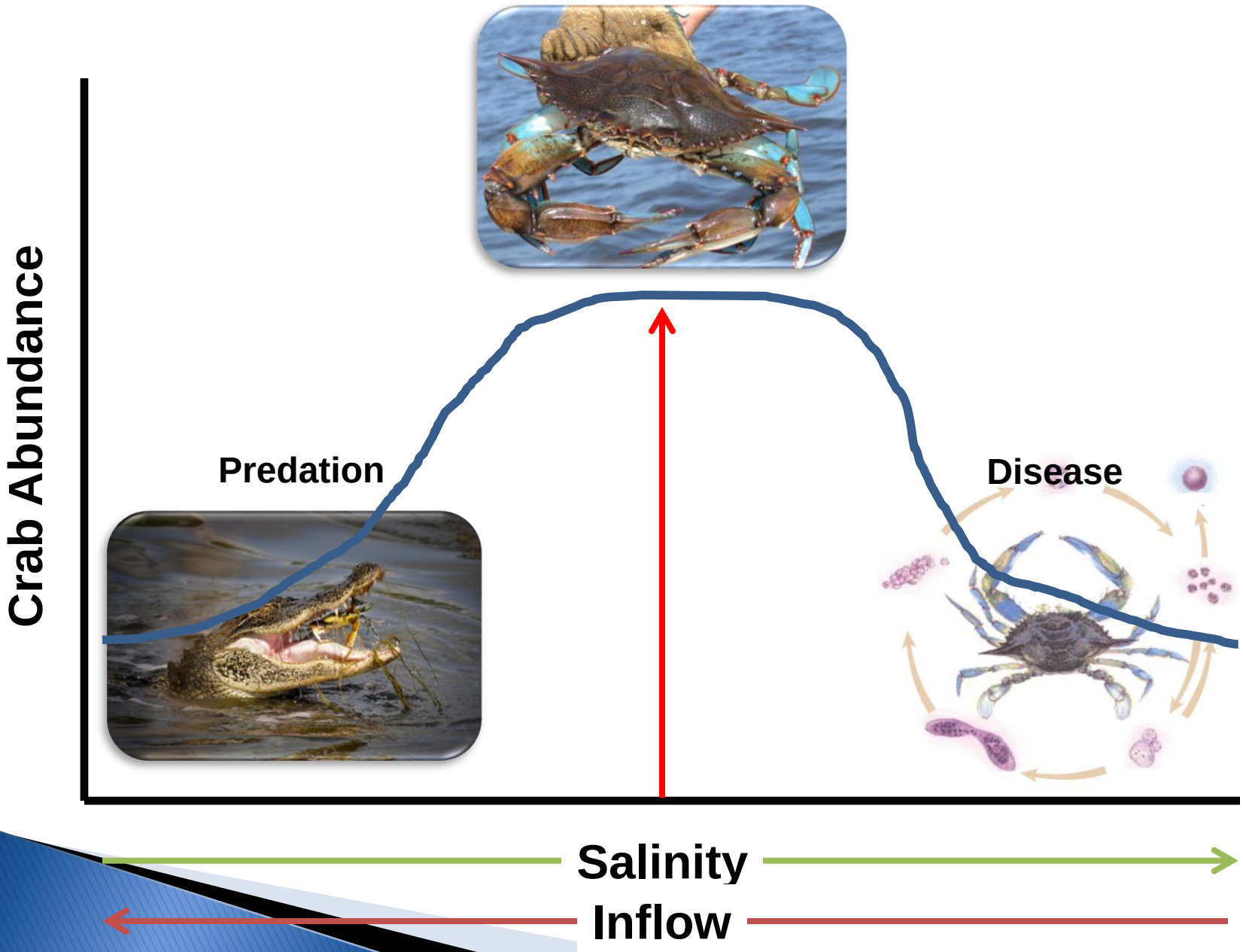

Crab Abundance Forecast
Crab number
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
2.5%
2.0%
1.5%
1.0%
0.5%
0.0%
Infection (%)
1975
1978
1981
1984
1987
1990
1993
1996
1999
2002
2005
2008
2011
2014
2017
2020
2023
2026
2029
2032
2035
2038
2041
2044
2047
2050
Year


Inflow
pH
Salinity
Temperature
Oxygen
Settlement
Survival
Predation
Disease
Abundance
Fish Effort
Landings

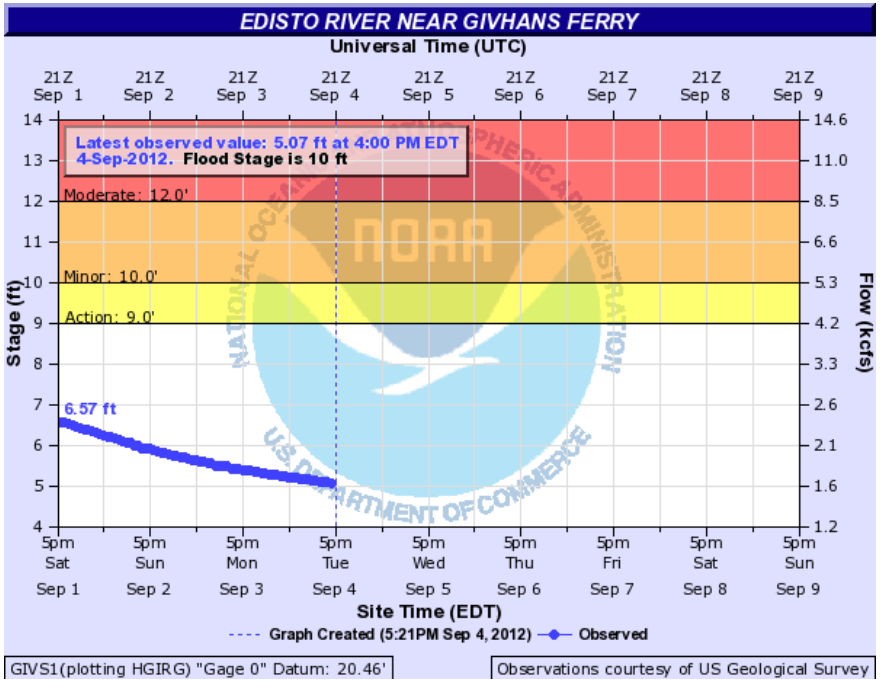
Presentation Outline

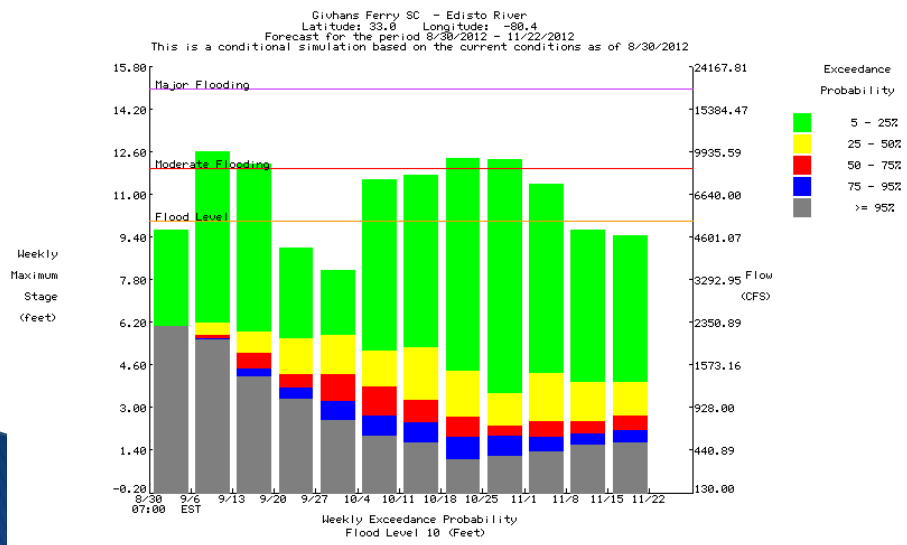
- Identification of the Problem – Dying of Thirst
- Crab Life History – Why Salinity Matters
- ACE Basin National Estuarine Research Reserve
- Patterns of Water Quality in Relation to Inflow
- Hypotheses Linking Crab Decline and Drought
- Forecasting the Future
- **What Can Management Do?**

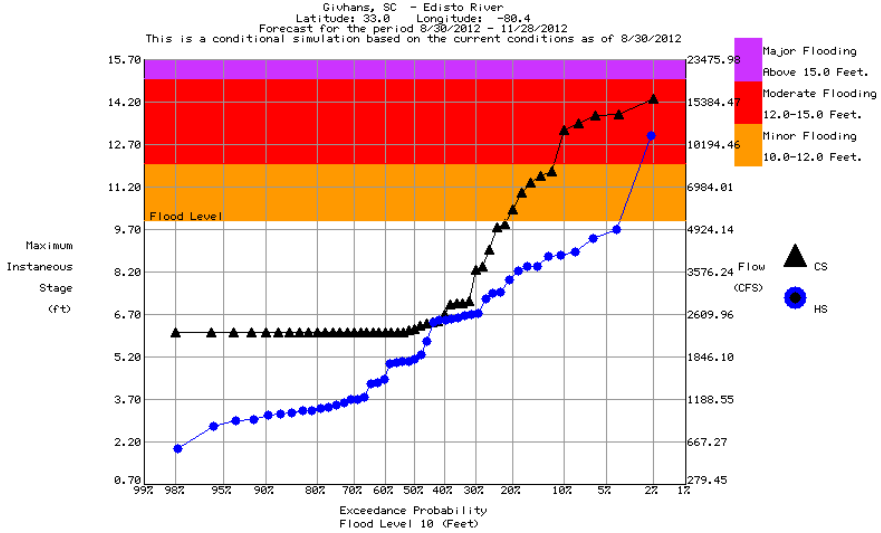


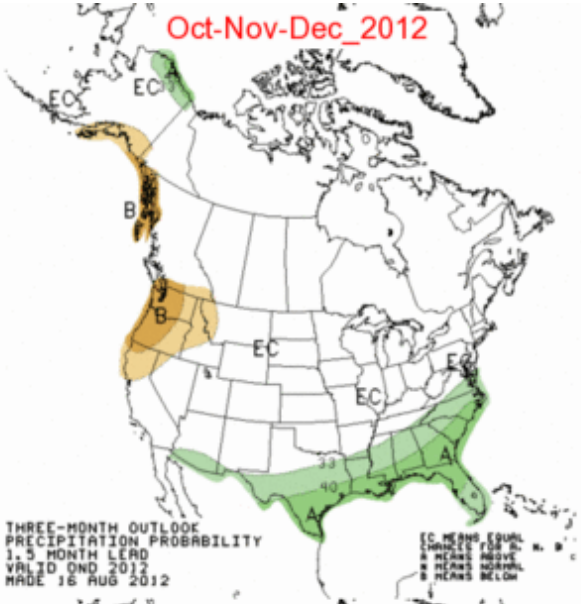

Crab Abundance
Predation
Disease
Salinity
Inflow

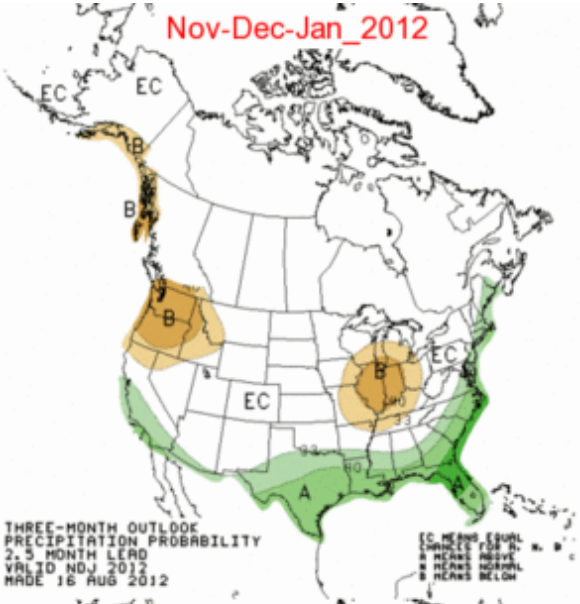

Sep 4, 2012 - 4:55 PM Eastern
CLICK ON NAME FOR MORE INFORMATION
Boiling Springs
Blacksburg
Cheraw
Greenville
Jocassee
Whitmire
Blair
Monteree Dam
Quinby
Pee Dee
Galivants Ferry
Pelzer
Camden
Effingham
Keowee
Parr Shoals
Chappells
Conway
Hartwell
Columbia
Carolina
Eastman
Lake Murray
Kingstree
Sandy Run
Lake Marion
Orangeburg
RB Russell Lake
Modoc
Thurmond
Jamestown
Givhans Ferry
Augusta
Burton's Ferry
Clyo
NOAA
NATIONAL WEATHER SERVICE
U.S. DEPARTMENT OF COMMERCE

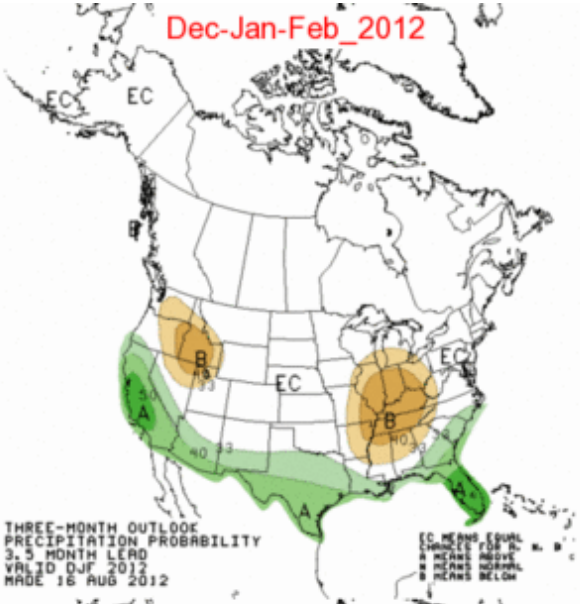

EDISTO RIVER NEAR GIVHANS FERRY
Universal Time (UTC)
21Z Sep 1
21Z Sep 2
21Z Sep 3
21Z Sep 4
21Z Sep 5
21Z Sep 6
21Z Sep 7
21Z Sep 8
21Z Sep 9
Latest observed value: 5.07 ft at 4:00 PM EDT 4-Sep-2012. Flood Stage is 10 ft
Moderate: 12.0'
Minor: 10.0'
Action: 9.0'
6.57 ft
Stage (ft)
Flow (kcfs)
5pm Sat Sep 1
5pm Sun Sep 2
5pm Mon Sep 3
5pm Tue Sep 4
5pm Wed Sep 5
5pm Thu Sep 6
5pm Fri Sep 7
5pm Sat Sep 8
5pm Sun Sep 9
Site Time (EDT)
Graph Created (5:21PM Sep 4, 2012)
Observed
GIVS1(plotting HGIRG) "Gage 0" Datum: 20.46'
Observations courtesy of US Geological Survey

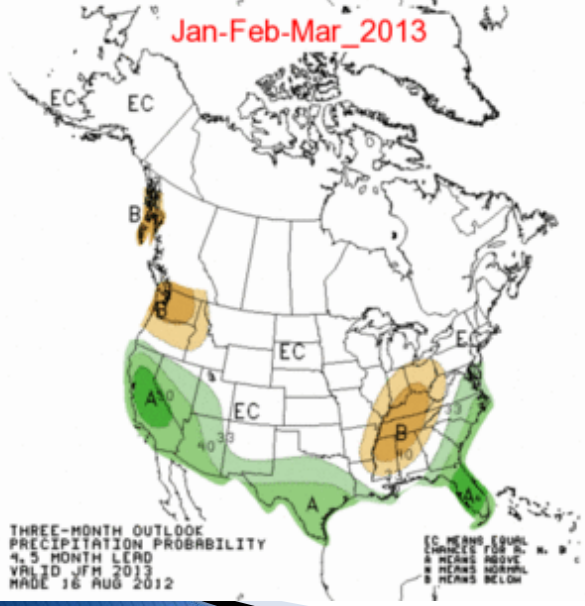

Givhans Ferry SC - Edisto River
Latitude: 33.0 Longitude: -80.4
Forecast for the period 8/30/2012 - 11/22/2012
This is a conditional simulation based on the current conditions as of 8/30/2012
Major Flooding
Moderate Flooding
Flood Level
Exceedance Probability
5 - 25%
25 - 50%
50 - 75%
75 - 95%
>= 95%
Weekly Maximum Stage (feet)
Flow (CFS)
8/30 07:00 EST
9/6
9/13
9/20
9/27
10/4
10/11
10/18
10/25
11/1
11/8
11/15
11/22
Weekly Exceedance Probability
Flood Level 10 (Feet)

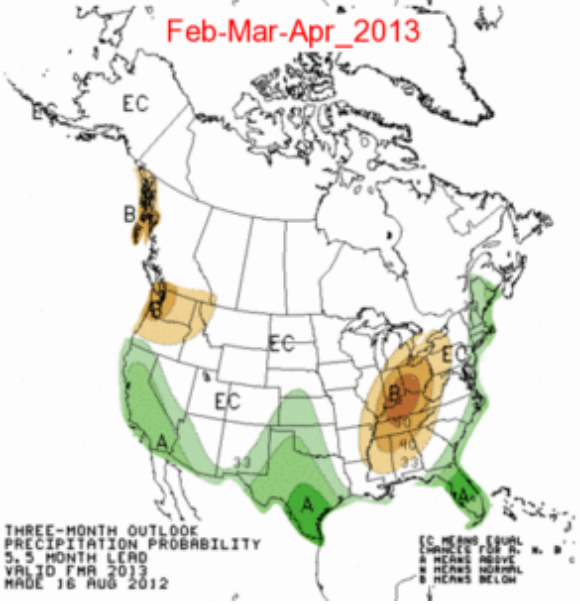

Givhans, SC - Edisto River
Latitude: 33.0 Longitude: -80.4
Forecast for the period 8/30/2012 - 11/28/2012
This is a conditional simulation based on the current conditions as of 8/30/2012
Major Flooding
Above 15.0 Feet.
Moderate Flooding
12.0-15.0 Feet.
Minor Flooding
10.0-12.0 Feet.
Flood Level
Maximum Instaneous Stage (ft)
Flow (CFS)
CS
HS
99% 98% 95% 90% 80% 70% 60% 50% 40% 30% 20% 10% 5% 2% 1%
Exceedance Probability
Flood Level 10 (Feet)

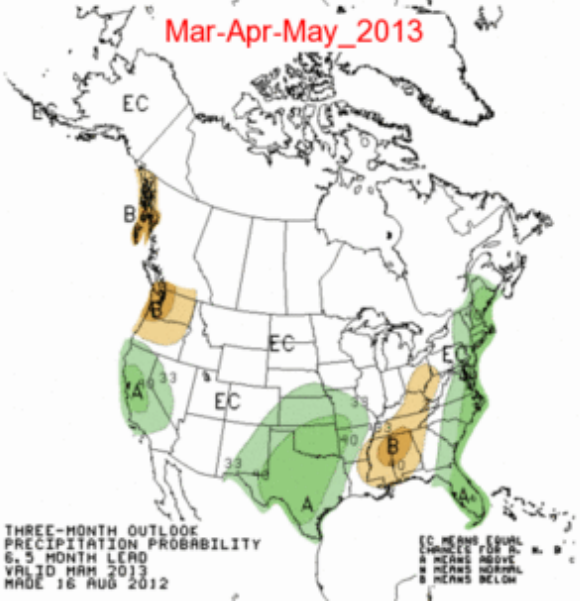

Oct-Nov-Dec_2012
THREE-MONTH OUTLOOK
PRECIPITATION PROBABILITY
1.5 MONTH LEAD
VALID OND 2012
MADE 16 AUG 2012

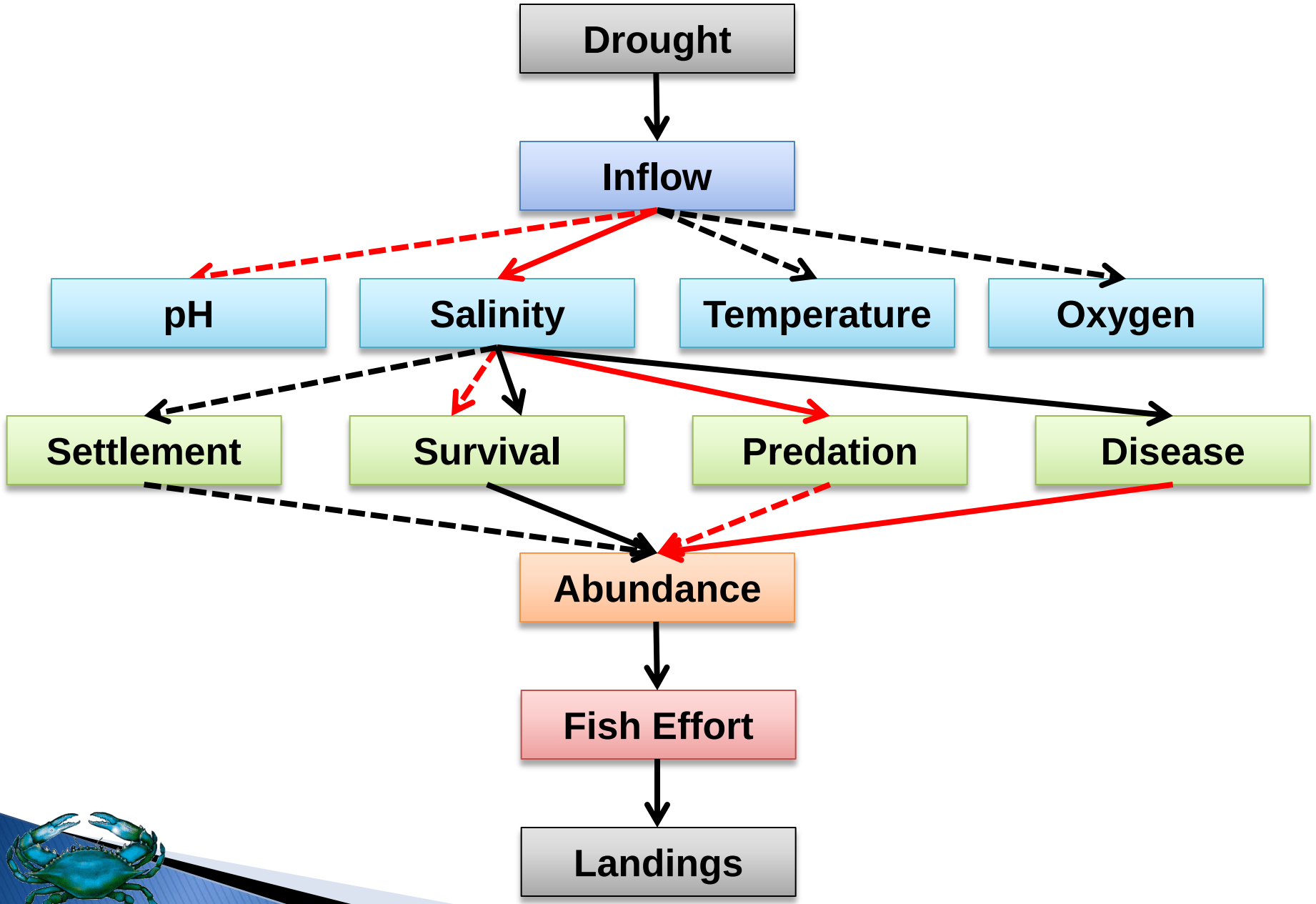

Nov-Dec-Jan_2012
THREE-MONTH OUTLOOK
PRECIPITATION PROBABILITY
2.5 MONTH LEAD
VALID NDJ 2012
MADE 16 AUG 2012


Dec-Jan-Feb_2012
THREE-MONTH OUTLOOK
PRECIPITATION PROBABILITY
3.5 MONTH LEAD
VALID DJF 2012
MADE 16 AUG 2012


Jan-Feb-Mar_2013
THREE-MONTH OUTLOOK
PRECIPITATION PROBABILITY
4.5 MONTH LEAD
VALID JFM 2013
MADE 16 AUG 2012

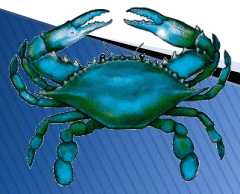

Feb-Mar-Apr_2013
THREE-MONTH OUTLOOK
PRECIPITATION PROBABILITY
5.5 MONTH LEAD
VALID FMA 2013
MADE 16 AUG 2012


Mar-Apr-May_2013
THREE-MONTH OUTLOOK
PRECIPITATION PROBABILITY
6.5 MONTH LEAD
VALID MAM 2013
MADE 16 AUG 2012


Drought
Inflow
pH
Salinity
Temperature
Oxygen
Settlement
Survival
Predation
Disease
Abundance
Fish Effort
Landings

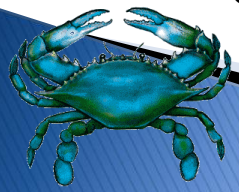
Conclusions

- River flow is negatively correlated with marsh salinity
- Salinity has both positive & negative effects on crabs
- Low salinity decreases survival & increases predation
- High salinity decreases survival & increases disease
- Impact of drought is dependent upon the initial flow rates of each individual river
- Models predict that decreasing flow below current levels will cause more declines in crab number than increases in crab number
- Managers should recommend minimum flow requirements to maintain healthy marsh ecosystem

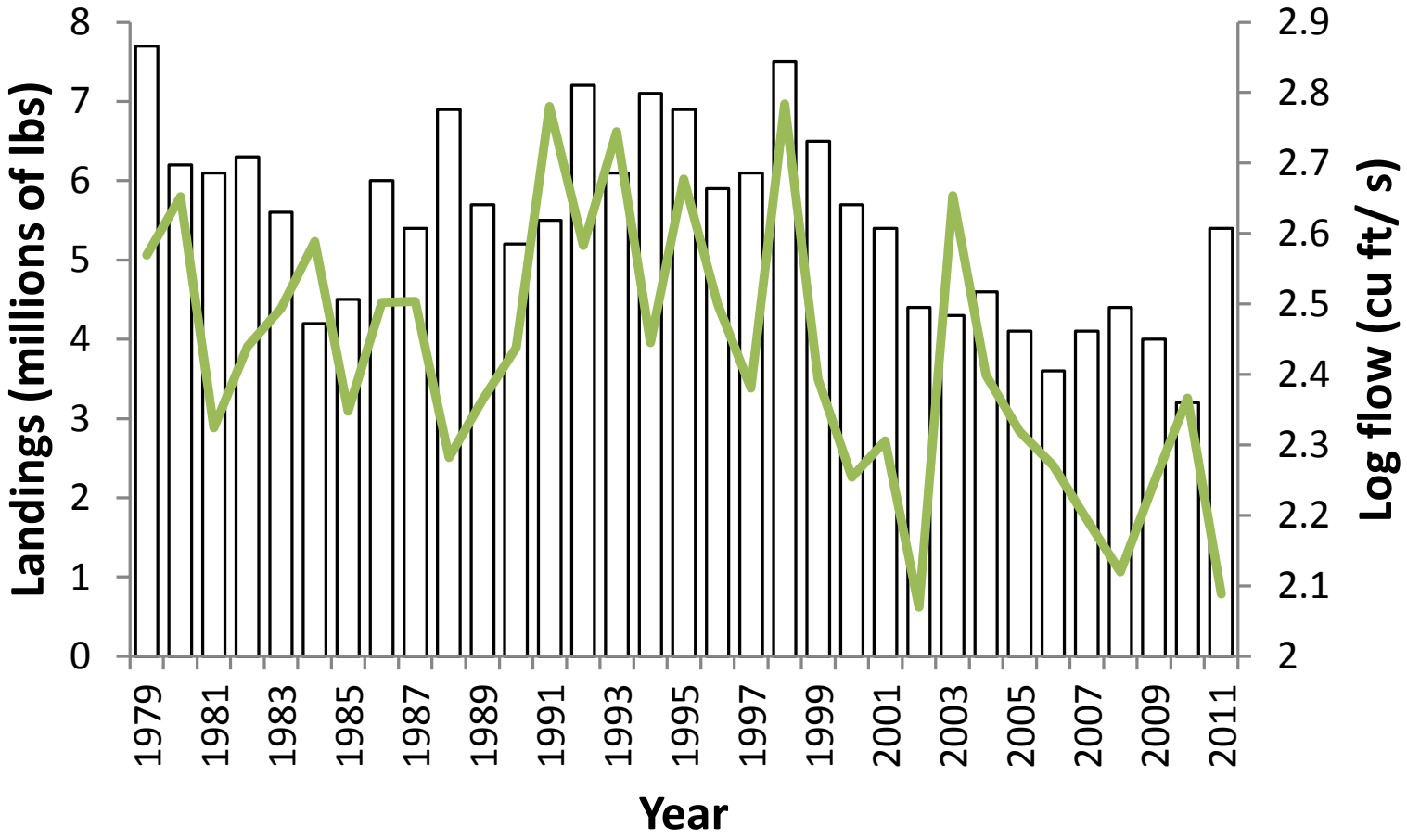


Acknowledgements

- Funding
  - Clemson University Research Incentive Fund
  - SC Sea Grant R/CF-15
  - NERR Graduate Research Fellowship
- Collaboration
  - ACE Basin NERR – Al Segars
  - SC DNR – John Leffler, Larry DeLancey
- Field assistants
  - Kylie Smith
  - Anna Gurley
  - Jennifer Micklewright
  - Kaighn Morlok
  - Tim Jordan
  - Joe Bisesi
  - Patrick Vigueira
  - Pete Bouwma
  - Conservation of Marine Resources Team

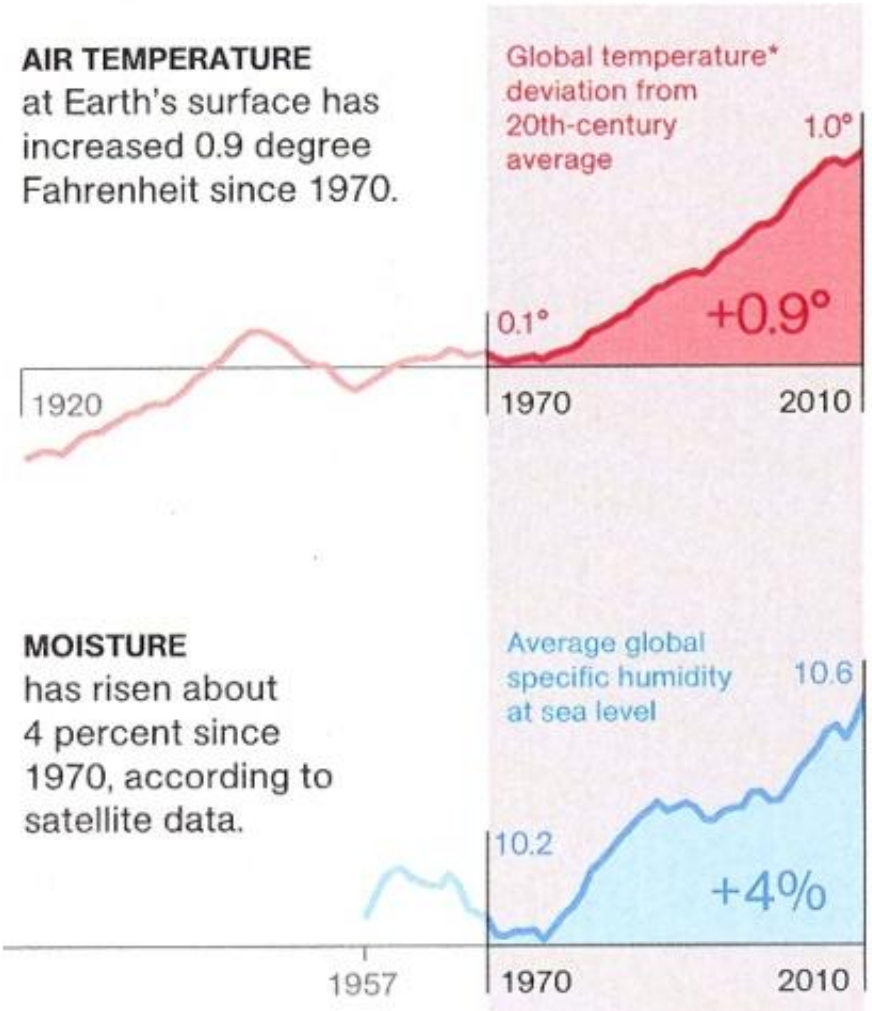


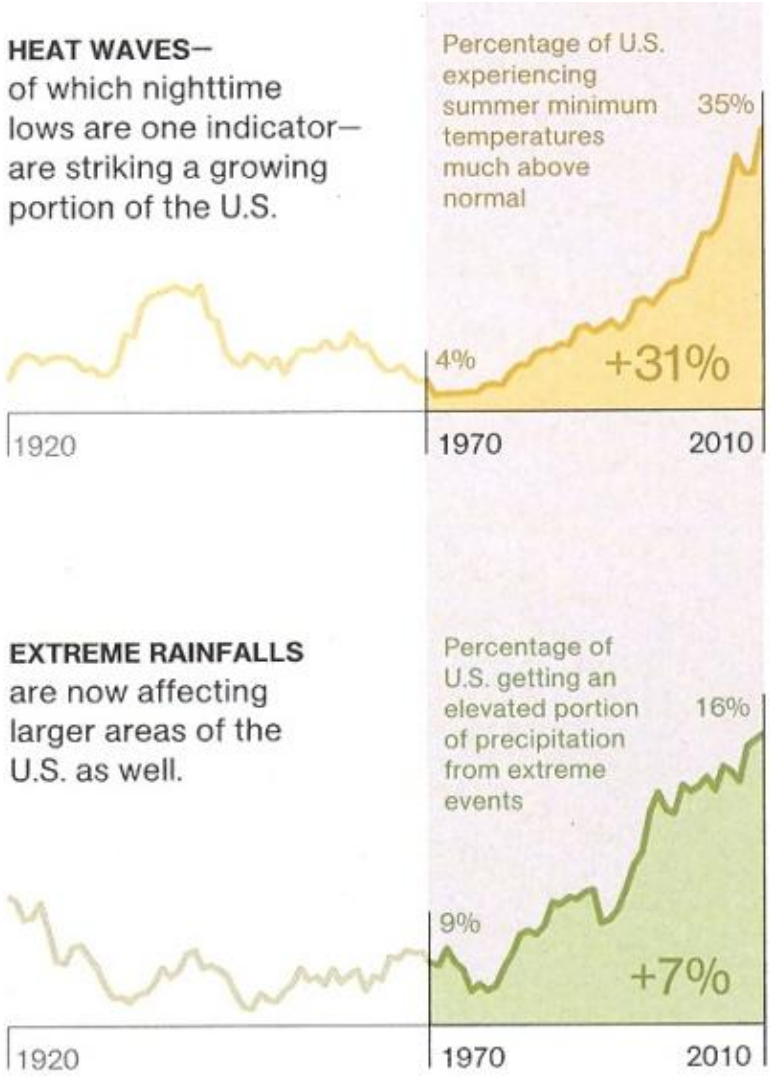
Why are blue crabs declining?



$r^2 = 0.211$, $p = 0.0072$

Climate Change





Miller Sept 2012 Nat Geo

BILLION-DOLLAR WEATHER

A chart of the most costly U.S. weather disasters shows nearly twice as many billion-dollar events since 1996 as in 1980-1995. The main reason: More people are living on higher-value properties in vulnerable places, such as coasts. But as the atmosphere warms, scientists expect destructive weather itself to become more common.

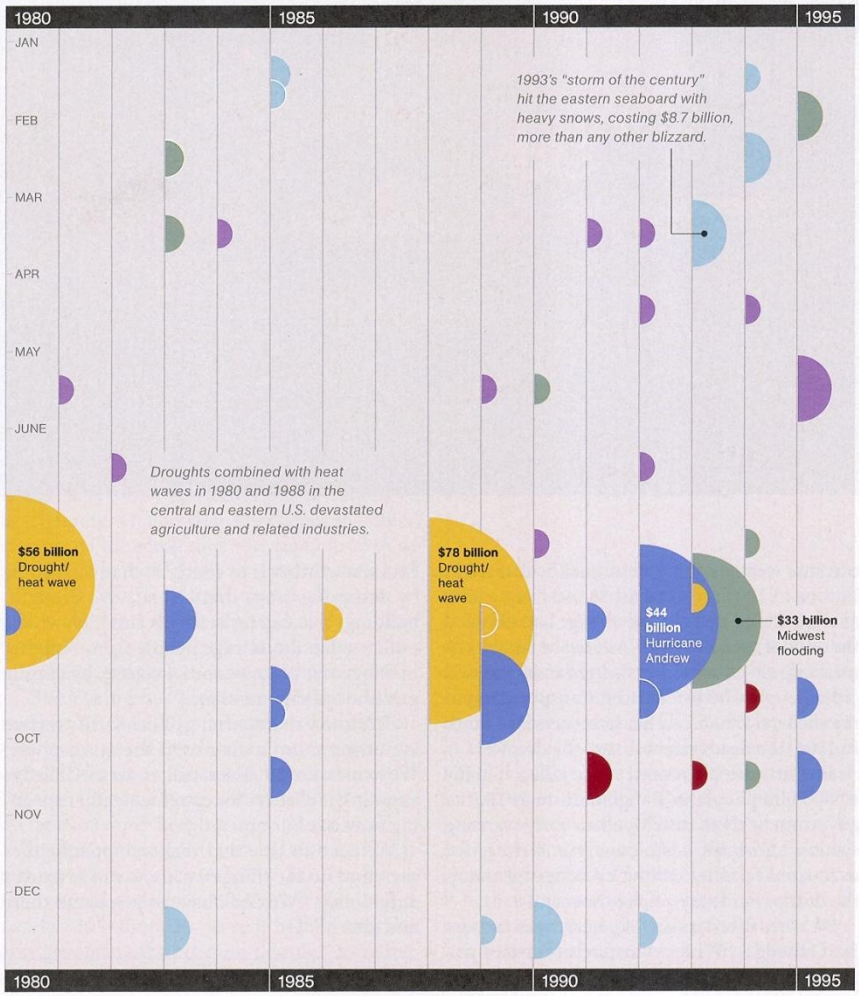
ALL U.S. WEATHER DISASTERS from 1980 to 2011 that caused at least one billion dollars* in damages are plotted by month and year; the size of each half circle represents the cost of the disaster. The ten most costly events are labeled.

COST OF DISASTER $50 BILLION, $20, $10

DISASTER TYPE
- Drought/heat wave
- Wildfire
- Flood
- Hurricane
- Tornado/hailstorm/thunderstorm
- Blizzard/ice storm/freeze

46 DISASTERS

Causing at least $1 billion in damages, 1980-1995



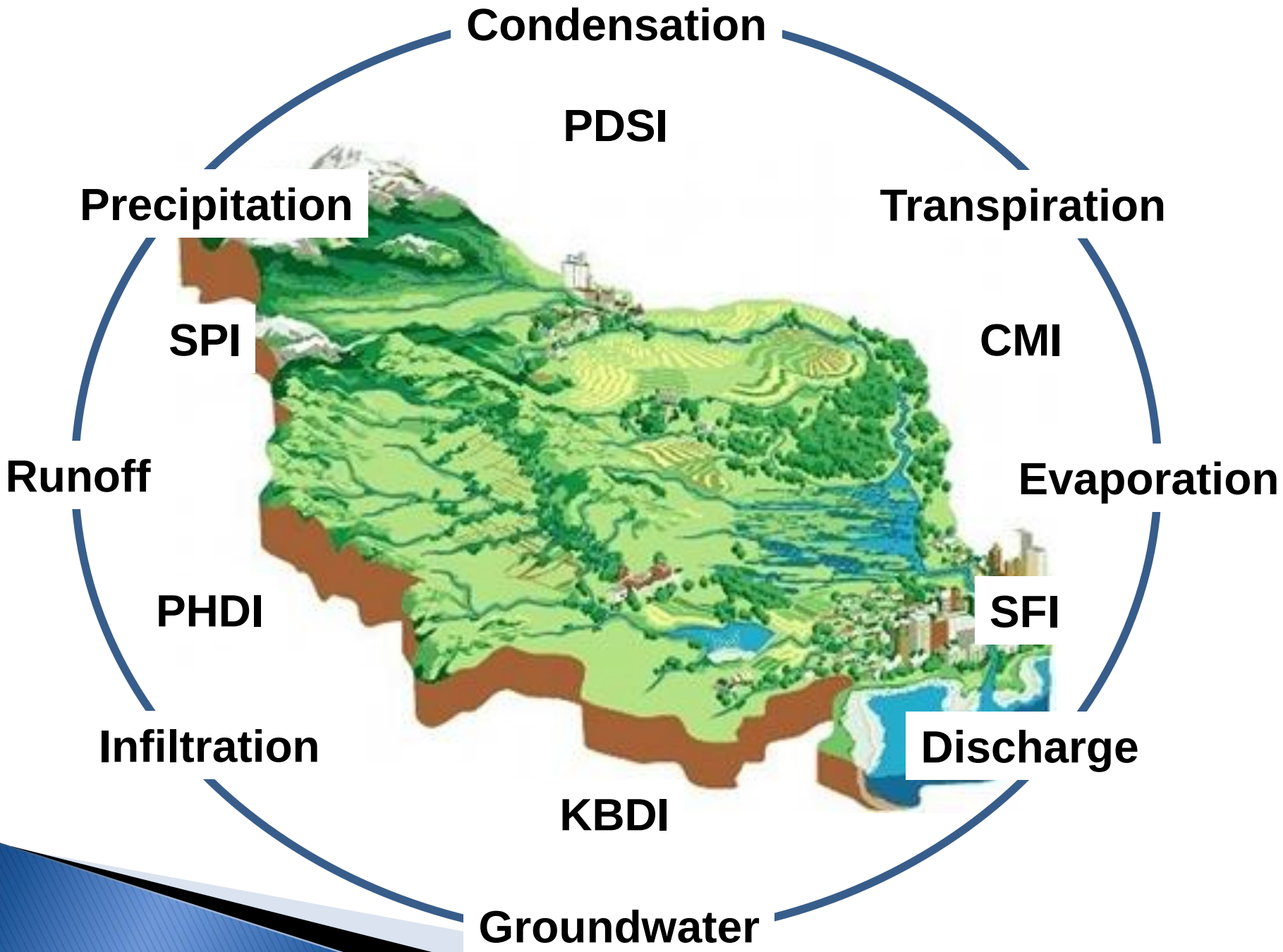
Total losses: $339 billion

87 DISASTERS

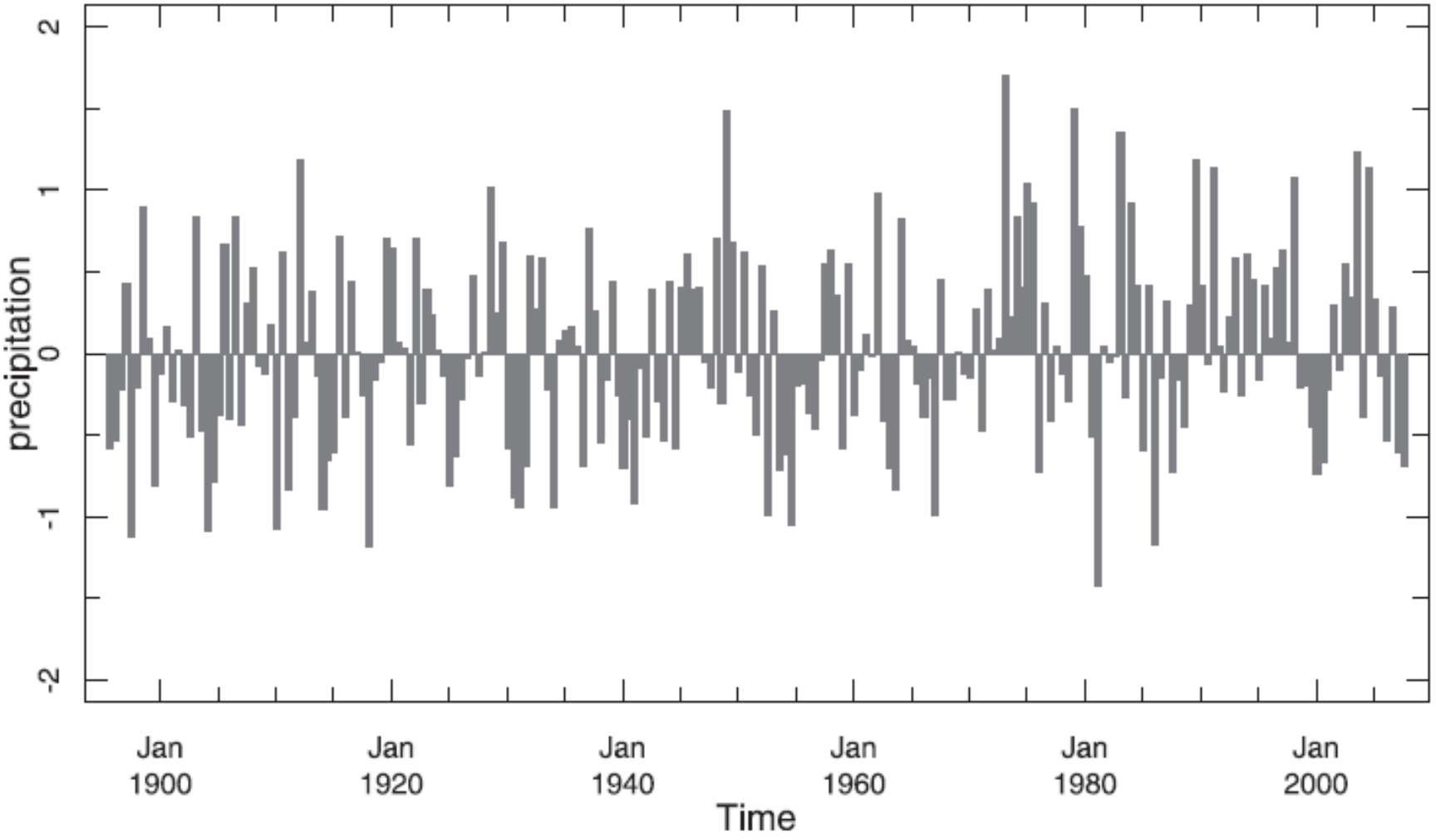
Causing at least $1 billion in damages, 1996-2011

Total losses: $541 b[illion]

Miller Sept 2012 Nat Geo

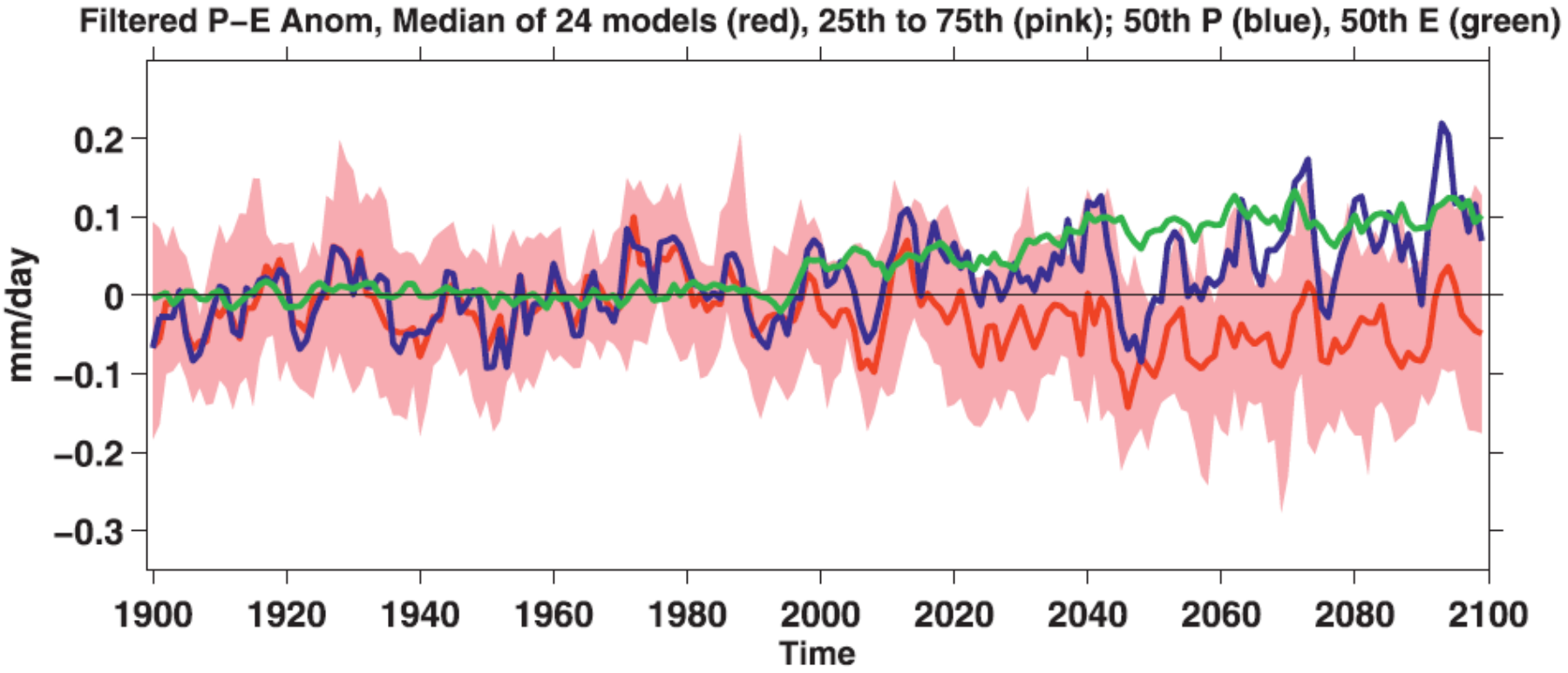

Condensation
PDSI
Precipitation
Transpiration
SPI
CMI
Runoff
Evaporation
PHDI
SFI
Infiltration
Discharge
KBDI
Groundwater

SE Precipitation Anomalies



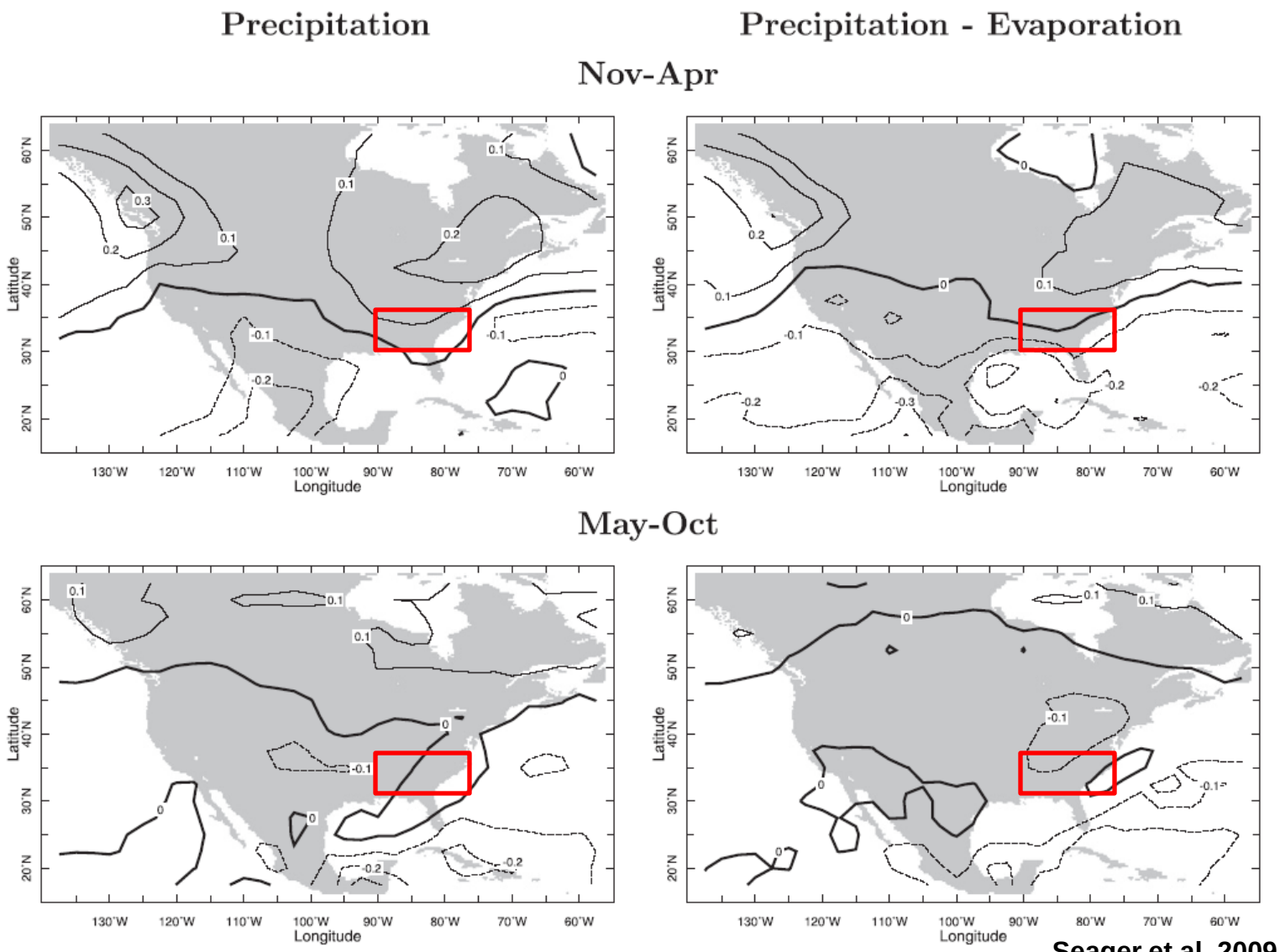
Seager et al. 2009 J Climate

SE P–E Forecast (24 models)



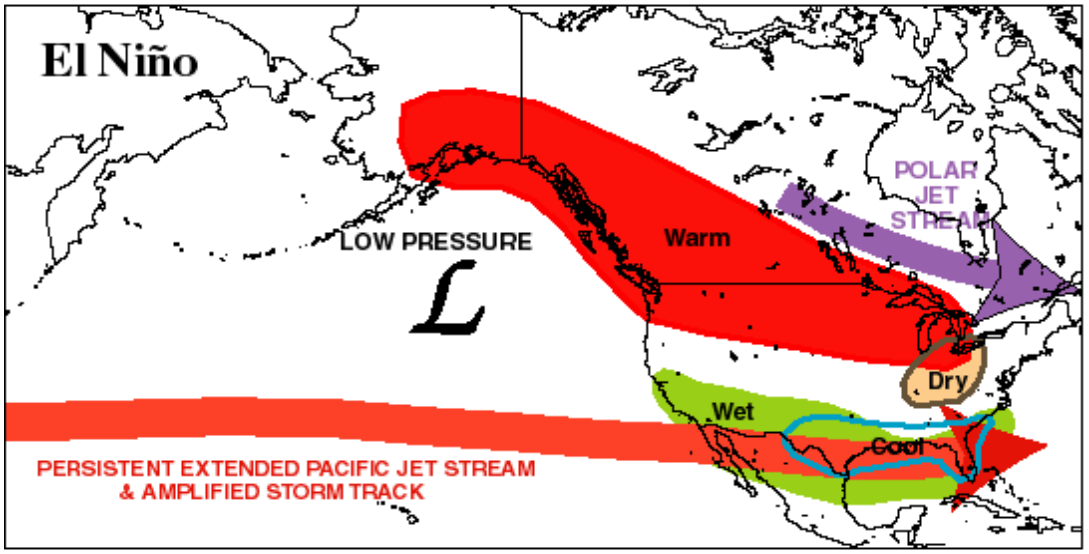
Seager et al. 2009 J Climate

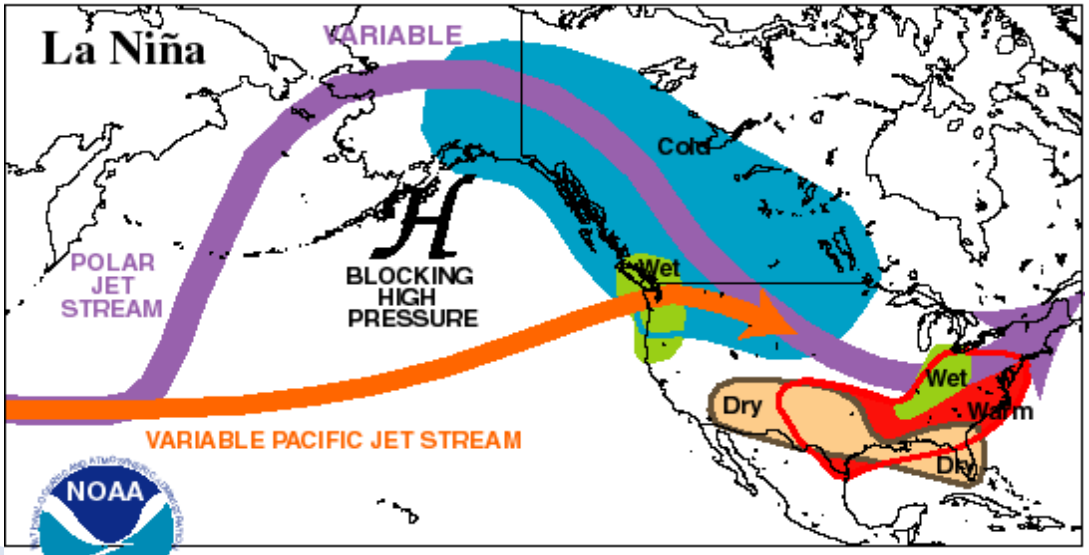
SE Drought Forecast (2020–2040)



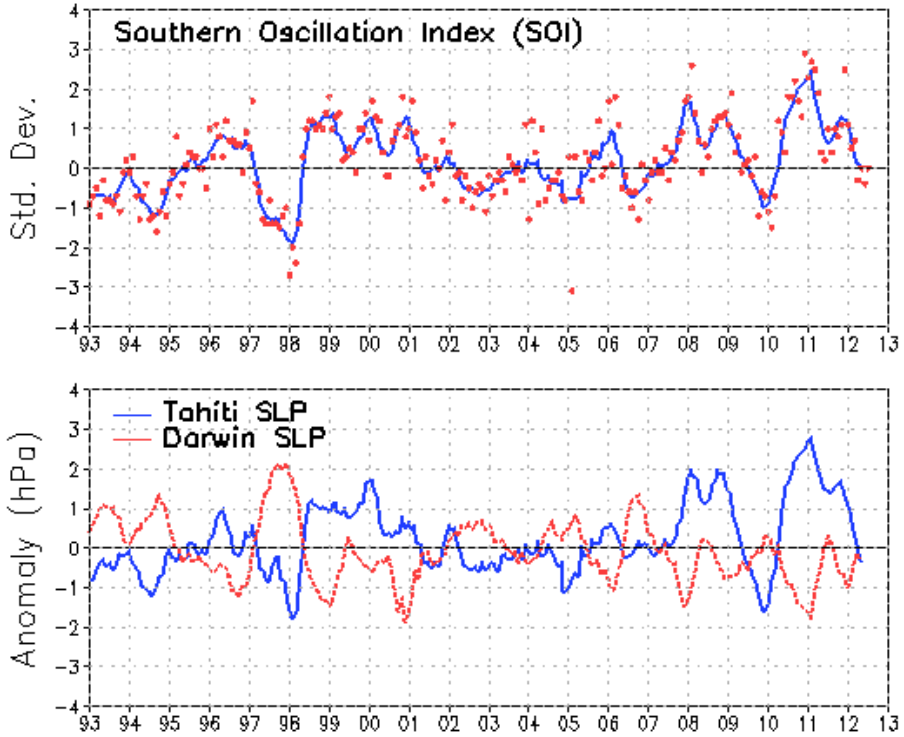
Seager et al. 2009 J Climate

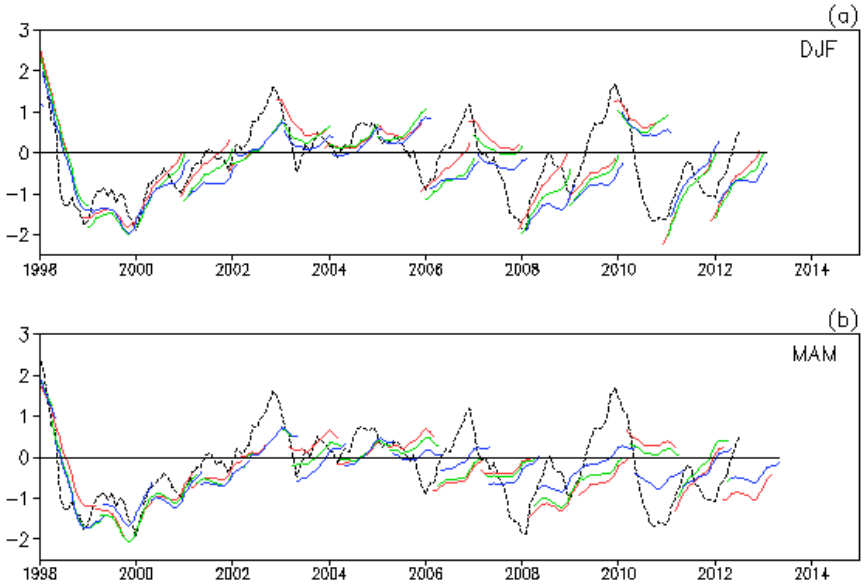
TYPICAL JANUARY-MARCH WEATHER ANOMALIES AND ATMOSPHERIC CIRCULATION DURING MODERATE TO STRONG EL NIÑO & LA NIÑA



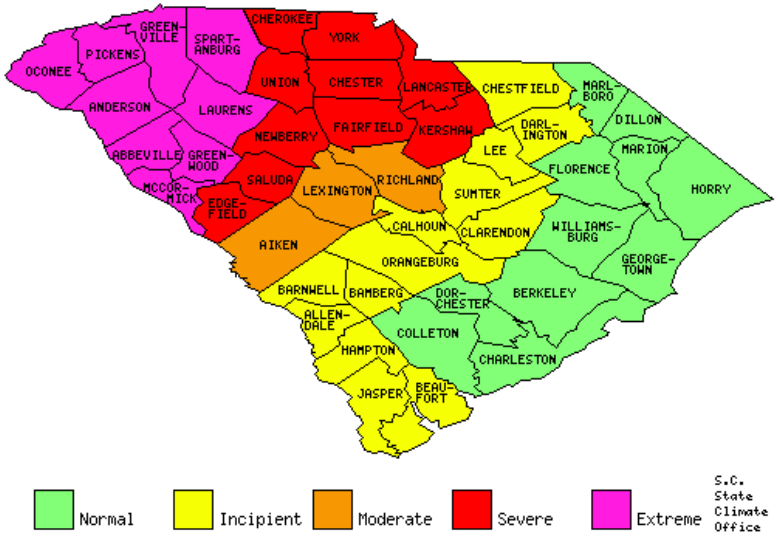


Climate Prediction Center/NCEP/NWS

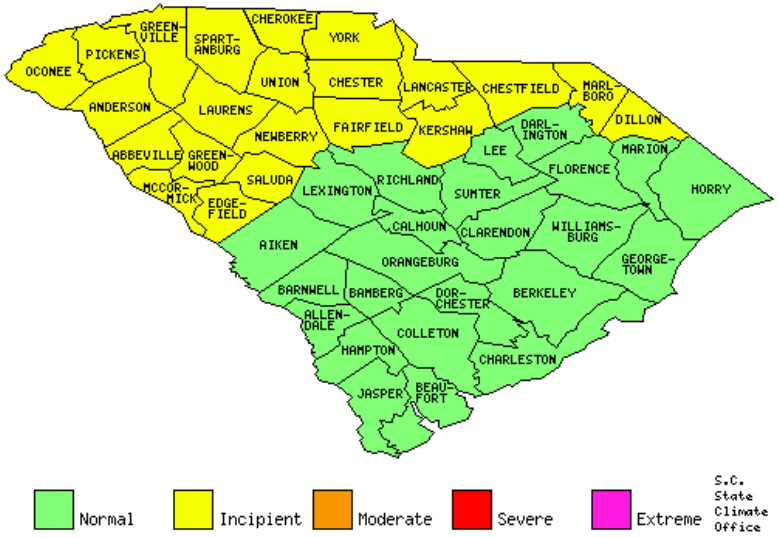

Southern Oscillation Index (SOI)
Std. Dev.
Tahiti SLP
Darwin SLP
Anomaly (hPa)
93 94 95 96 97 98 99 00 01 02 03 04 05 06 07 08 09 10 11 12 13


(a)
DJF
(b)
MAM
1998 2000 2002 2004 2006 2008 2010 2012 2014

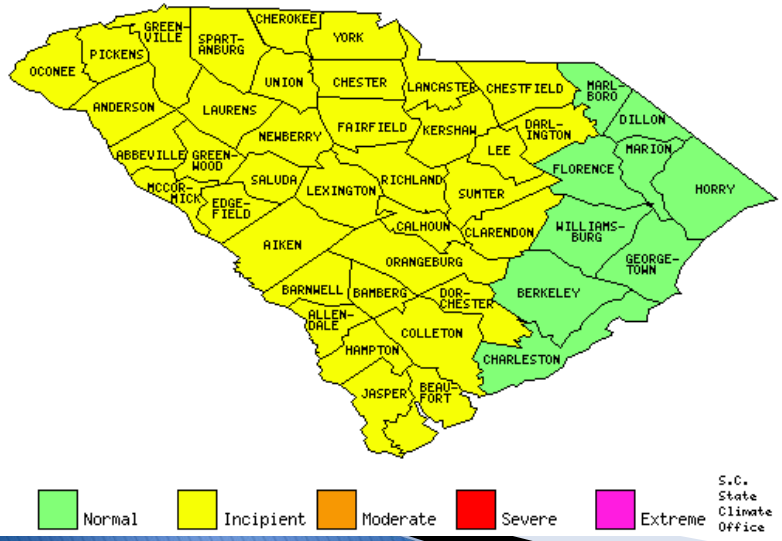
South Carolina Drought Status by County
September 16, 2008



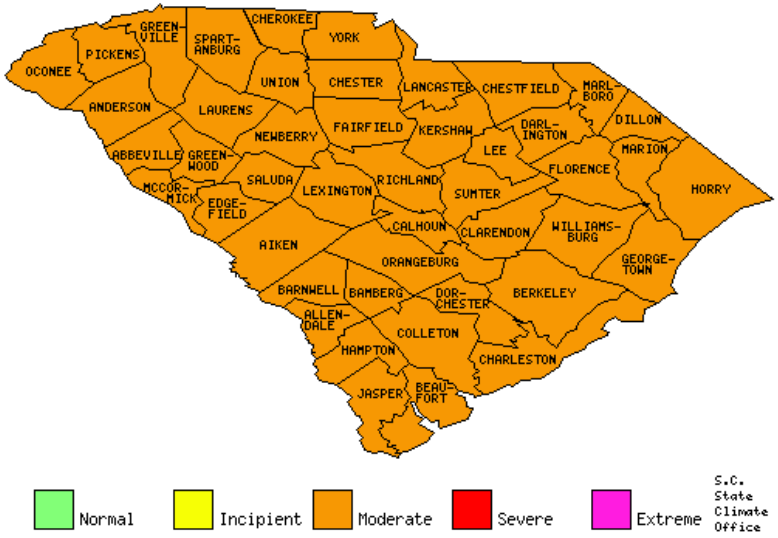
South Carolina Drought Status by County
September 2, 2009



South Carolina Drought Status by County
October 7, 2010



South Carolina Drought Status by County
September 8, 2011

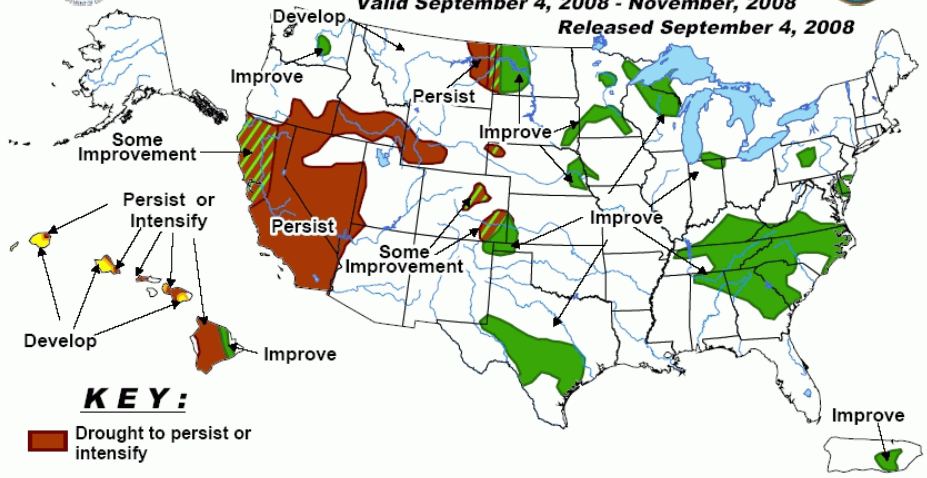


U.S. Seasonal Drought Outlook

Drought Tendency During the Valid Period

Valid September 4, 2008 - November, 2008

Released September 4, 2008



KEY:

- Drought to persist or intensify
- Drought ongoing, some improvement
- Drought likely to improve, impacts ease
- Drought development likely

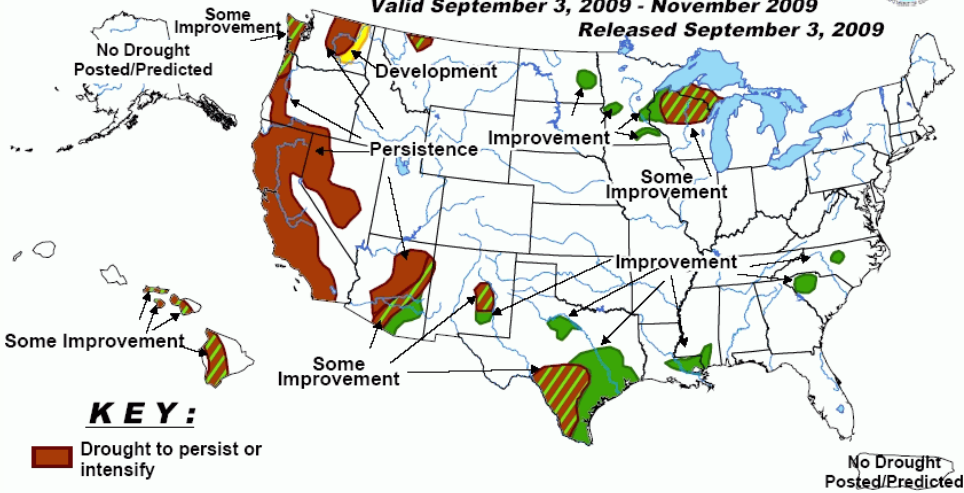
Depicts large-scale trends based on subjectively derived probabilities guided by short- and long-range statistical and dynamical forecasts. Short-term events -- such as individual storms -- cannot be accurately forecast more than a few days in advance. Use caution for applications -- such as crops -- that can be affected by such events. "Ongoing" drought areas are approximated from the Drought Monitor (D1 to D4 intensity). For weekly drought updates, see the latest U.S. Drought Monitor. NOTE: the green improvement areas imply at least a 1-category improvement in the Drought Monitor intensity levels, but do not necessarily imply drought elimination.

U.S. Seasonal Drought Outlook

Drought Tendency During the Valid Period

Valid September 3, 2009 - November 2009

Released September 3, 2009



KEY:

- Drought to persist or intensify
- Drought ongoing, some improvement
- Drought likely to improve, impacts ease
- Drought development likely

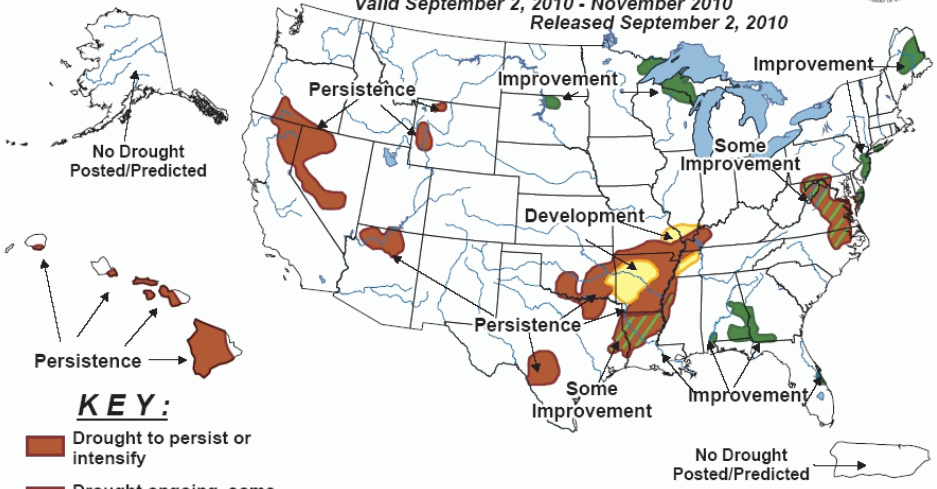
Depicts large-scale trends based on subjectively derived probabilities guided by short- and long-range statistical and dynamical forecasts. Short-term events -- such as individual storms -- cannot be accurately forecast more than a few days in advance. Use caution for applications -- such as crops -- that can be affected by such events. "Ongoing" drought areas are approximated from the Drought Monitor (D1 to D4 intensity). For weekly drought updates, see the latest U.S. Drought Monitor. NOTE: the green improvement areas imply at least a 1-category improvement in the Drought Monitor intensity levels, but do not necessarily imply drought elimination.

U.S. Seasonal Drought Outlook

Drought Tendency During the Valid Period

Valid September 2, 2010 - November 2010

Released September 2, 2010



KEY:

- Drought to persist or intensify
- Drought ongoing, some improvement
- Drought likely to improve, impacts ease
- Drought development likely

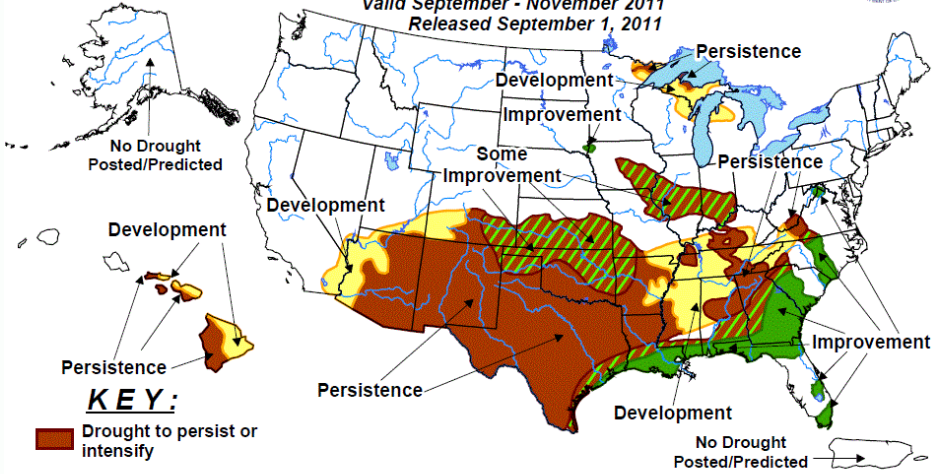
Depicts large-scale trends based on subjectively derived probabilities guided by short- and long-range statistical and dynamical forecasts. Short-term events -- such as individual storms -- cannot be accurately forecast more than a few days in advance. Use caution for applications -- such as crops -- that can be affected by such events. "Ongoing" drought areas are approximated from the Drought Monitor (D1 to D4 intensity). For weekly drought updates, see the latest U.S. Drought Monitor. NOTE: the green improvement areas imply at least a 1-category improvement in the Drought Monitor intensity levels, but do not necessarily imply drought elimination.

U.S. Seasonal Drought Outlook

Drought Tendency During the Valid Period

Valid September - November 2011

Released September 1, 2011



KEY:

- Drought to persist or intensify
- Drought ongoing, some improvement
- Drought likely to improve, impacts ease
- Drought development likely

Depicts large-scale trends based on subjectively derived probabilities guided by short- and long-range statistical and dynamical forecasts. Short-term events -- such as individual storms -- cannot be accurately forecast more than a few days in advance. Use caution for applications -- such as crops -- that can be affected by such events. "Ongoing" drought areas are approximated from the Drought Monitor (D1 to D4 intensity). For weekly drought updates, see the latest U.S. Drought Monitor. NOTE: the green improvement areas imply at least a 1-category improvement in the Drought Monitor intensity levels, but do not necessarily imply drought elimination.


Mature male


Immature Female


Gravid Female


Mature Female